DEMONSTRATION AND VALIDATION OF THERMAL SPRAY VITRIFICATION OF LEAD-CONTAINING PAINT ON STEEL STRUCTURES

by

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13. ABSTRACT *(Maximum 200 words)*
In the past, red lead primer was used to control corrosion on many common steel structures maintained by the Department of Defense (DoD). Thermal spray vitrification (TSV) technology has been demonstrated as a way to remove lead-based paint coatings from steel substrates that are not suitable for overcoating.

In the TSV process, lead-based paints are thermally sprayed with a specially-formulated powdered glass feedstock that absorbs and encapsulates lead. When the glass solidifies and cools, it cracks and falls off. This waste product is collected and remelted onsite to complete the vitrification process. The final waste product is nonhazardous as determined by the Toxic Characteristic Leaching Procedure, and can be disposed of as a nonhazardous waste or recycled into value-added products.

This report documents demonstrations of TSV conducted on a bridge at the Rock Island Arsenal, IL, and an aircraft hangar door at Marine Corps Base Kaneohe Bay, HI. The objectives of these demonstrations were to remove lead-containing paint from steel structures, meet applicable environmental and worker health and occupational safety standards, enable recoating of the substrate, collect data, and estimate production rates.

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Foreword

This study was conducted for the Environmental Security Technology Certification Program (ESTCP) under Project 9607 "Thermal Spray Removal of Lead-Based Paint." The technical monitor was Dr. Jeffrey Marqusee.

The work was performed by the Materials Science and Technology Branch (CF-M) of the Facilities Technology Division (CF), U.S. Army Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Ashok Kumar. Ray Zatorski is with Zatorski Coatings Co., Inc. A portion of this work was supported by an appointment to the Research Participation Program at CERL administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the Department of Energy and CERL. Dr. Ilker Adiguzel is the Chief, CECER-CF-M, and L. Michael Golish is Facilities Chief, CECER-CF. The CERL technical editor was Gordon L. Cohen, Technical Information Team.

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I. Executive Summary

In the past, red lead primer was used to control corrosion on many common steel structures maintained by the Department of Defense (DoD), including bridges, aircraft hangars, water storage tanks, metal buildings, fire hydrants, and structural steel. When lead-based paint on such structures may not be coated over because of peeling, it must be removed before surface preparation and repainting. To remove lead-based paint by abrasive blasting, a tight containment structure is required to prevent the lead dust from contaminating air, soil, and water. Inside such containment structures, increased worker protection is required because of high dust concentrations. These containment structures are expensive and time-consuming to erect, and the required worker protection equipment likewise time-consuming and cumbersome to use. These factors drive up paint-removal costs by reducing worker productivity.

In the thermal spray vitrification (TSV) process, molten glass is sprayed on painted steel using off-the-shelf thermal spray equipment with powdered glass feedstock specially formulated to absorb and encapsulate lead. When it solidifies and cools on the steel substrate, thermal stresses cause the glass to crack and fall off. This waste product is collected and remelted on site to complete the vitrification process. The final waste product is nonhazardous as determined by the Environmental Protection Agency's Toxic Characteristic Leaching Procedure. It can then be disposed of as a nonhazardous waste or recycled into value-added products.

Demonstrations of TSV were recently conducted on a bridge at the Rock Island Arsenal, IL, and an aircraft hangar door at Marine Corps Base Kaneohe Bay, HI. The objectives of these demonstrations were to (1) remove lead-containing paint in the field from steel structures, (2) meet all applicable environmental safety standards, (3) meet all applicable worker health and occupational safety standards, (4) enable recoating of the substrate using a surface-tolerant coating system, and (5) collect data and estimate production rates. All objectives were met in both demonstrations.

The TSV production rate in the Rock Island demonstration was estimated at 30 sq ft per hour and an estimated cost ranging from \$3.50 to \$10.00 per sq ft, with an average cost of \$4.96 per sq ft. The production rate in the Kaneohe Bay aircraft hangar demonstration door was estimated at 35 sq ft per hour, with an average cost of \$3.50 per sq ft.

The waste glass from TSV can be recycled using commercial processes that convert the slag waste into nonhazardous value-added glass or ceramic products such as abrasives, construction materials, and refractory insulating materials. It is expected that TSV would fit a niche market that includes surface preparation for zone painting on large bridge structures or for small fixed structures such as fire hydrants where the cost of the containment structure cannot be spread over a large area.

II. Technology Description

Red lead primer has been used on many steel structures to control corrosion. Commonly used structures in the DoD that may contain lead-based paint include bridges, catwalks, towers, water storage tanks, oil tanks, piping, steel doors, trusses, exterior railings, steel posts, poles, stairways, handrails, cranes, pontoons, and boiler plant structural members. In addition to the DoD facilities infrastructure, ship structures and bilges have been painted with lead pigmented coatings. When lead-based paint shows evidence of peeling, removal is required. During the removal process, a containment structure is required to keep the lead dust from contaminating the air, soil or water. Inside tight containment structures, increased worker protection is required due to the higher dust concentrations. Containment structures and protective equipment reduce worker productivity.

This project demonstrated and validated the thermal spray vitrification (TSV) process to remove lead-based paint from DoD steel structures such as a section of a bridge at the Rock Island Arsenal. In TSV, specially formulated molten glass is applied using the thermal spray torch to the painted steel substrate. The molten glass reacts with the paint and the lead from the paint adheres to the glass surface. Due to thermal stresses, the glass cracks and falls off the substrate removing the lead. Following remelting, the glass is classified as nonhazardous. The principal advantage of the process is that airborne lead dust or vapors are not produced. As a result, TSV reduces the cost of environmental compliance and worker health protection associated with lead-based paint removal from DoD structures (Ref. 1-3).

The cost of removal and disposal of lead-based paint from flat surfaces on steel structures using abrasive blasting in a containment structure is estimated to be $5-18 per sq ft . This cost may climb to $100 per sq ft depending on the area, surface complexity, and other requirements such as working over water or in the presence of machinery. The disposal cost of the hazardous waste is about $4 per sq ft. The cost of using TSV to remove lead-based paint from steel structures is estimated to be about $5 per sq ft.

The estimated surface area of steel structures at Army facilities such as water tanks, bridges, aircraft hangars, antennas, ladders, poles, railings, catwalks, metal buildings, etc., is about 118 million sq ft. Most of this steel is coated with red lead oxide primer to protect it from corrosion. The cost analysis, based on data collected during the demonstration, estimated the cost of thermal spray vitrification process to range from $3.50 to $12.00 per sq ft with an average cost of about $5.00 per sq ft. This is $3.00 per sq ft cheaper than the currently used abrasive blasting at an average cost of $8.00 per sq ft. If we assume that 10% of the painted steel structures at Army facilities need removal and half can uses this process, the process is applicable to 5.9 million sq ft of steel. Based on a benefit of $3 per sq ft, the estimated savings to the Army are $17,700,000.

DoD wide, the facilities benefit is estimated at $30 million over the next 10 years for the 200,000,000 sq ft of steel structures coated with lead-based paint.

TSV uses commercially available thermal spray equipment. The individual system components include the hand-held torch, powder feeder, gas manifold, gas flow controllers, and pressure regulators. The system consumes compressed air, fuel gas, oxygen, and the glass powder. The system is connected using hoses and is shown schematically in Figure B-1. The pressure and flow of all the gasses are controlled by regulators and flow meters. These gas flow parameters are set to predetermined values and the gases are mixed and combusted in the torch nozzle, where the powder is introduced. The resulting flame is in excess of 2000 °C (3600 °F). Powder is fed and controlled by the powder feeder. The transport mechanism for the powder from the feeder to the gun's nozzle is compressed air. The powder melts in the flame and is propelled toward the substrate. When the powder impacts on the surface, the glass splat cools and combines with the paint. The surface temperature of the substrate is maintained at less than 230 °C (450 °F).

Glass powder is sprayed onto the lead-containing paint for removal and vitrification using an oxy-acetylene thermal spray apparatus. This technology was patented by the US Army in U. S. Patent No. 5,292,3758, A. Kumar and J. Petreanu.(Ref. 3, 4, 5) The iron boro-silicate glass composition was developed by the US Army Construction Engineering Research Laboratory (CERL) in conjunction with the Department of Energy, Savannah River Technology Center (Ref. 6). The glass composition produces a stable and durable waste product that can immobilize up to 25 percent of its own weight of lead oxide. This waste product has a leaching rate as measured by the Toxicity Characteristic Leaching Procedure (TCLP) of less than 5 parts per million (ppm). In laboratory tests, the glass also has been shown to immobilize chromium, cadmium and copper.

Upon cooling, the difference in the coefficient of thermal expansion between the glass and the substrate causes the glass to crack and spall from the surface. Several applications of glass may be required to remove all the layers of paint. In the demonstrations, one to three passes of the thermal spray process were needed to remove the paint.

The heat of TSV will cause warping during the glass application, on steel with thin cross-section of approximately 3.4 mm (0.134 in.). This issue was addressed by the use of a commercial device that uses compressed air and water. An air-water mist is directed on the backside of thin steel sections during processing. This keeps the backside cool and reduces or eliminates warping. The air-water mixture is set to cool without condensing on the surface. The Kaneohe Bay work successfully demonstrated the use of mist cooling to mitigate the warping of thin steel substrates.

The glass fragments, that were less than 5 to 8 cc (2 to 3 in.) in size, fall into a sheet metal pan for collection. In some areas, the glass was removed with a blow from a chipping hammer. A vacuum-equipped needle gun with high-efficiency particulate air (HEPA) filter was used to clean crevices and remove loose mil scale and other loose detrimental foreign matter.

Collected glass was then remelted in a separate furnace onsite, which completes the vitrification process by immobilizing the lead inside the glass network. The final product has a concentration of lead leachate as determined by TCLP analysis of less than 5 ppm, which is the regulatory limit for classification for hazardous waste.

The remelt process to complete vitrification uses a high-temperature furnace, stirrers, safety equipment, and water bath. The procedure based on previous work and the results of TCLP tests consists of the following steps:

1. Add the waste from the TSV process to the furnace until full.
2. Stir every 15 minutes after melting occurs.
3. Heat the furnace to at least 800 °C (1470 °F) and maintain for 1 hour.
4. Shut off the heat and furnace cool the waste.
5. After cooling, reheat the furnace to at least 800 °C (1470 °F) and maintain for 1 hour.
6. Remove the molten glass from the container by pouring or by use of utensils into water.
7. As soon as the danger of scalding is past, remove the glass from the water using separate utensils to prevent cross contamination.
8. Test the cooled waste material using TCLP analysis.
9. Dispose of the glass through appropriate channels when the material passes TCLP analysis.

The remelt process may be repeated if the glass waste does not pass the TCLP analysis.

TSV has been tested on carbon steel panels coated with a red lead primer, Federal Specification TT-P-86H; and alkyd top coat, Federal Specification TT-E-489 at the Rock Island Bridge Demonstration. TSV was tested on carbon steel panels coated with a red lead primer, Federal Specification TT-P-86H; a phenolic resin, aluminum-pigmented top coat, Federal Specification TT-P-38; and an alkyd topcoat, Federal Specification TT-E-489 at the Kaneohe Bay Hangar Door Demonstration. These are the most common topcoat systems used on Federal highway and Army bridges. TSV was successful in removing lead-containing paint regardless of the topcoat system.

TSV removes paint and restores the surface of steel to the profile as it was before painting. Rust is also removed in the TSV process leaving a dull finish that meets the Steel Structures Painting Council (SSPC) Specification SSPC 3, "Power Tool Cleaning." This surface finish is acceptable

for surface-tolerant coating in atmospheric exposure. The life of the newly coated surface should provide 25-year performance.

The TSV process is intended only for removal of lead-containing paint from steel. This technology is not appropriate for removing lead-containing paint from wood, concrete, or masonry because of the relatively high process temperature and the potential to damage the substrate.

Initially, the goal was to reduce the lead on the treated steel surface to less than 1 milligram per square centimeter (mg/cm^{2}). However, achieving this goal required many passes of the torch and caused thermal damage to the steel substrate. Further evaluation during the demonstration showed that even residual lead levels this low could produce hazardous levels of lead dust within the containment structures required for abrasive blasting during the next painting cycle. Therefore, the final goal was to remove most of the lead-containing paint while leaving a surface satisfactory for the application of a surface-tolerant coating. This level of TSV performance could be highly useful as a surface preparation technique in overcoating applications.

Overcoating — the practice of painting over existing an coating to extend service life — is much less expensive than complete removal of lead-containing paint. The average equivalent annual cost for overcoating is $1.04/sq ft using a three-coat alkyd system versus $1.99/sq ft for total removal and repainting with an inorganic zinc/polyurethane system. The tradeoff with overcoating, of course, is that it may fail catastrophically or may not provide the desired level of corrosion protection. Acceptance criteria for overcoating applications are as follows:

Visual assessment of percent rusting. Maximum rusting of 10% (rust rating of 4) for typically degraded areas and 17% (rust rating of 3) for most severely degraded points of the structure are recommended. The work necessary to clean and paint structures corroded to this degree approaches that required for standard coating removal, and the performance of the applied overcoat system is unlikely to be as good as that of a new paint system. Therefore, structures corroded to a greater extent are excellent candidates for TSV for surface preparation.

Coating thickness and adhesion. The risk of overcoating failure can be determined by measuring the thickness and adhesion of the existing coating. The risk of overcoating failure increases as film thickness increases and adhesion decreases. For example, if the existing coating is 20 mils thick and the adhesion, as determined by ASTM D3359 testing, is 1A or 1B, then the risk of overcoating failure is high, and such a coating would be a good candidate for TSV removal.

Patch testing. ASTM D 5064 and SSPC Guide 9, Section 6.2.2, provide details about patch testing. Ideally the test patch period should span at least one winter. Delaminated test patches imply a very high risk of coating failure. An intermediate level of risk is indicated by poor or

reduced levels of intercoat or base coat adhesion. Coatings associated with these results are also good candidates for the TSV paint removal process.

The quality of surface preparation for overcoating is critical. The specific method should be selected to minimize damage to the aged coating while providing a clean surface free of contaminants, corrosion, and loose coating. Sweep and brush-off blasting may disrupt adhesion or fracture the aged coating, which may lead to failures of the overcoat system. High-pressure water cleaning coupled with vacuum-shrouded power tool cleaning is often used on surfaces with rusting greater than 3% but less than 10%. If the rusting is greater than 10 percent, then removal by abrasive blasting or the TSV process is recommended, based on the area requiring treatment. The cost of containment structures can be reduced if the structure is large (i.e., a surface area greater than 10,000 sq ft). Smaller structures are good candidates for TSV paint removal.

III. Demonstration Design

A. Performance Objectives

The main performance objectives for this series of demonstrations were:

1. Remove lead-containing paint from a steel structure,
2. Meet all applicable environmental standards,
3. Meet all applicable worker health and occupational safety standards,
4. Be able to recoat the substructure using a surface-tolerant coating system, and
5. Allow for data collection to estimate the production costs.

B. Physical Setup and Operation

Site selection for the demonstration of the thermal spray vitrification process was based on the following factors:

1. A steel structure with lead-containing paint,
2. The structure's design shall be typical to that found on other DoD installations,
3. Paint system shall be similar to that used at other DoD installations, and
4. A site willing to actively participate and assist in the demonstration.

Sampling and analysis found that the Viaduct Bridge located at the Rock Island Arsenal is coated with a lead-containing primer and alkyd top coats. This is a commonly used lead-containing paint system for atmospheric exposure for steel structures in the Department of Defense (DOD) as well as in the Department of Transportation (DOT). The bridge design is typical of Federal highway and Army bridges. The site actively participated and assisted in the demonstration. The Rock Island District on behalf of the Rock Island Arsenal administered the contract for the demonstration. This included preparing the Contract Solicitation and Specification document as well as conducting an environmental and safety review of the contract, the bid solicitation, the contractor selection, and the contract award. The Rock Island District also assisted U.S. Army Construction Engineering Research Laboratory in obtaining regulatory acceptance of TSV from the State of Illinois Environmental Protection Agency.

The demonstration was conducted on a steel bridge at the Rock Island Arsenal, IL. The Viaduct Bridge connects the Rock Island Arsenal and the City of Rock Island and has two lanes for vehicle traffic. TSV was demonstrated on a section of a horizontal steel beam below the traffic deck of the bridge.

Site/Facility Maps and Photographs for the Rock Island Bridge Demonstration are shown in Appendix C:

Figure B-1. Schematic of the thermal spray system.
Figure B-2. Use of thermal spray vitrification process to remove lead-containing paint from the Viaduct Bridge at the Rock Island Arsenal.
Figure B-3. Location plan of Rock Island Arsenal.
Figure B-4. Detailed location plan of the bridge.
Figure B-5. Drawing of the bridge.
Figure B-6. Containment structure built for the demonstration.
Figure B-7. The Viaduct Bridge at the Rock Island Arsenal after the TSV demonstration was completed.

Additional sampling and analysis found that the hangar door at Marine Corps Base, Hawaii at Kaneohe Bay, HI is coated with a lead-containing primer and various top coats. This type of paint system is commonly used on hangar doors and other steel infrastructure within the DoD and the Department of Transportation (DOT) for steel structures in atmospheric exposure. The door is representative of hangars in the DoD. The site is an active hangar building for helicopter repair and maintenance. Zatorski Coating Company, Inc. (ZCC) developed a system using water mist that reduces warpage due to heat from TSV on thin cross section steel. This successful demonstration can lead to immediate implementation of the technology on hangar doors. This technology has demonstrated rapid deployment and rapid removal of paint that improves facility readiness. TSV has low implementation costs for small areas since there is no need for containment structures.

CERL awarded the thermal spray removal contract to the Zatorski Coatings Company, Inc. This included preparing the Contract Solicitation and Specification document as well as conducting an environmental and safety review of the contract, the bid solicitation, and contract award.

The hangar door at the Marine Corps Base was on a portion of Hangar 3, Building 103 which was undergoing rehabilitation. This provided a challenge for lead-containing paint abatement since the floor was newly refinished adjacent to the interior of the hangar door.

Site/Facility maps and photographs for the Kaneohe Bay Hangar Door Demonstration are shown in Appendix C:

Figure B-8. Diagram of a typical door section at Hangar 3, Building 103
Figure B-9. Photograph of Hangar Door and Building from the Southeast
Figure B-10. Drawing of Site Layout of the Marine Corps Base
Figure B-11. Photograph of Hangar Door Exterior before TSV

Figure B-12. Photograph of Hangar Door Interior before TSV
Figure B-13. Photograph of Hangar Door Showing Dents and Warpage of the Skin Plate before TSV
Figure B-14. Photograph of Hangar Door Interior After TSV and Repainting Showing No Additional Warpage
Figure B-15. Photograph of Exterior of Hangar Door after TSV and Repainting
Figure B-16. Photograph of Hangar Door Interior after TSV Repainting

C. Monitoring Procedures

1. Rock Island Bridge Demonstration

As stated in the demonstration plan for the Rock Island Bridge Demonstration, paint evaluation and testing was conducted by personnel from the Paint Technology Center at the U.S. Army Construction Engineering Research Laboratory. Evaluation was conducted of the existing paint system, the surface after the application of TSV, and the newly painted surface. Worker health monitoring was conducted by the US Army Center for Health Promotion and Preventive Medicine (USACHPPM), Aberdeen, MD.

Evaluation of the existing paint system included dry film thickness measurement using American Society for Testing and Materials (ASTM) D 1186 "Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base." The Positector Model 5002-F thickness gauge was used to measure the film thickness. The adhesion of the existing paint system was determined using ASTM D 3359 "Standard Test Method for Measuring Adhesion by Tape Method." The 150 sq ft of surface was subdivided into a grid containing 15 sections each with a surface area of approximately 10 sq ft. Thickness and adhesion measurement was conducted within each grid area. The sampling requirements in each of the ASTM standard test methods, ASTM D 1186 and ASTM D 3359, were utilized. Personnel from CHPPM sampled the existing paint system and performed total metal and TCLP analysis.

Following thermal spray vitrification process, and prior to repainting, the surface profile was compared to visual standards from the Steel Structures Painting Council, SSPB-VIS-1-89 "Visual Standards for Abrasive Blast Cleaned Steel (Standard Reference Photographs)." The profile was also evaluated using ASTM D 4417 "Standard Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel. Following repainting, the paint was inspected in accordance with the requirements for Paint System No. 16 in the COE Guide Specification CEGS 09940, "Painting: Hydraulic Structures."

Personnel from the USACHPPM, Industrial Hygiene Field Services Program (IHFSP) conducted the sampling for worker health monitoring. Air samples included analysis of metals, dust, crys-

talline silica, and combustion products. A combination of direct reading and indirect reading (i.e., requiring laboratory analysis) methods was used. The upwind air samples were used to assess the background chemical concentrations. The personal air samples were used to assess actual exposures - such information was used for comparison to occupational airborne exposure limits. The downwind air samples were used to assess diluted chemical concentrations downwind from the plume - such information was used to determine potential exposures to others in close proximity. The source air samples were used to capture the rising plume, where emission concentrations would be at the highest - such information was used to assess potential worst-case exposures and to ascertain the amount of dilution occurring at other sampling sites.

Occupational chemical exposures were compared to the OSHA Permissible Exposure Limits (PEL) and American Conference of Governmental Industrial Hygienist (ACGIH) Threshold Limit Values (TLV). Metal leachate from the solid Vitrified Paint Remelt samples were compared to EPA Toxicity Characteristic Leaching Procedure regulatory levels, i.e., Title 40 Part 261.24, Toxicity Characteristic, Table 1 - Maximum Concentration of Contaminants for the Toxicity Characteristics.

2. Kaneohe Bay Hangar Door Demonstration

As stated in the demonstration plan for the Marine Corps Base, Hawaii hangar door, personal air sampling was collected to provide an exposure assessment for the TSV process and the needle gun process. Area samples were collected to assess work practices and lead emissions. The area samples were collected downwind from the TSV processing during both the glass application and remelting operation. The samples were collected on 0.8 micrometer, mixed cellulose ester filters, using 37 mm, three-piece cassettes. These samples were collected by William N. Albrecht, Ph.D., CIH.

CERL and consultants for CERL (Corrosion Control Consultants and Labs, Inc.) conducted the paint evaluation and testing. These evaluations included the existing paint systems, the surface after TSV and the newly painted surface.

The existing paint system was evaluated by the American Society for Testing and Materials (ASTM) D 1186, "Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base". A thickness film gage was used to measure the film thickness. The adhesion of the existing paint system was determined using ASTM D 3359, "Standard Test Method for Measuring Adhesion by Tape Method". An excess of 3 thickness and adhesion measurements were made on the hangar door. The amount of lead per unit area was measured with a commercial X-ray fluorescence gage.

The surface was inspected after TSV for adequate cleanliness and surface profile for painting. The surface was compared to the SSPB-VIS-1-89, "Visual Standards for Abrasive Blast Cleaned Steel" which are standard reference photographs. Following repainting, the paint was inspected in accordance with the requirements for Paint System N. 16 in the Corps of Engineers Guide Specification GEGS 09940, "Painting: Hydraulic Structures".

The sampling procedures were conducted in accordance with the demonstration and sampling plans.

D. Analytical Procedures

Analysis of the samples from the Rock Island Bridge Demonstration was performed by a certified laboratory for the USACHPPM in accordance with analytical methods references in the Rock Island Bridge Demonstration plan.

The personal air samples and area samples from the Kanehoe Bay Hangar Door Demonstration were analyzed for lead according to NIOSH Method 7300. The respirable dust level was measured by the NIOSH Method 600.

The analytical procedures were conducted in accordance with the Kaneohe Bay Hangar Door Demonstration and sampling plans.

E. Demonstration Site/Facility Background and Characteristics

Site selection for the TSV demonstration was based on the following factors: (1) A steel structure with lead-containing paint, (2) The structure's design shall be typical to that found on other DoD installations, (3) Paint system shall be similar to that used at other DoD installations, and (4) A site willing to actively participate and assist in the demonstration.

1. Rock Island Bridge Demonstration

Sampling and analysis found that the Viaduct Bridge located at the Rock Island Arsenal is coated with a lead-containing primer and alkyd top coats. This is a commonly used lead-containing paint system for atmospheric exposure for steel structures in the Department of Defense (DOD) as well as in the Department of Transportation (DOT). The bridge design is typical of Federal highway and Army bridges. The site actively participated and assisted in the demonstration. The Rock Island District on behalf of the Rock Island Arsenal administered the contract for the demonstration. This included preparing the Contract Solicitation and Specification document as well as conducting an environmental and safety review of the contract, the bid solicitation, the contractor selection, and the contract award. The Rock Island District also assisted U.S. Army Con-

struction Engineering Research Laboratory in obtaining regulatory acceptance of TSV from the State of Illinois Environmental Protection Agency.

The demonstration was conducted on a steel bridge at the Rock Island Arsenal, IL. The Viaduct Bridge connects the Rock Island Arsenal and the City of Rock Island and has two lanes for vehicle traffic. TSV was demonstrated on a section of a horizontal steel beam below the traffic deck of the bridge.

The Rock Island Bridge Demonstration required the construction of a temporary scaffolding to permit worker access to the underside of the bridge. The construction specification called for the containment to comply with the requirements of Steel Structures Painting Council (SSPC) Guide 6, Class 3C, Table 1. In addition to the containment required by the specification, the contractor provided full containment in accordance with SSPC 6, Class 1C, Figure B-6.

Table 1. Comparison of containment and ventilation system components (SSPC).

Containment System	Class 1C	Class 3C
Containment Materials	Rigid or Flexible	Rigid or Flexible
Penetrability	Air Impermeable or Chemical Resistant	Chemical Resistant
Support Structure	Rigid or Flexible	Minimal
Joints	Full Seams	Partial Seal
Entryway	Overlap	Open Seam
Air Makeup	Open	Open
Forced or Natural	Forced or Natural	Natural
Air Pressure	Not Required	Not Required
Air Movement	Not Specified	Not Specified
Exhaust Dust Filtration	Filtration	Not Required

Electrical power was supplied by a portable gasoline powered generator. Electrical power was used for the task lighting and for the PM 10 air monitors. Compressed air was provided for the powder feeder, the HEPA equipped power tools, and for the paint spray gun.

The location of the demonstration site is shown in Figures B-3 and B-4. The demonstration was conducted on the first three panels of the eastern most bridge girder on the north (river) side of Pier No 8, Figure B-5. Scaffolding was constructed to provide access to the girder. A ramp provided access to the scaffolding from the levy that abuts Pier No. 8. Bottles of oxygen, and acetylene used by thermal spray process were stored in a secure fenced area on the opposite side of Pier No. 8. The air compressor, electrical generator, and air filtration unit were deployed on top of the levy near the bridge, approximately 20 to 30 feet from the scaffolding. The powder feeder was placed on the scaffolding during application of the thermal spray process. Storage

sheds were also placed on the levy near the work site. The principal equipment used by the contractor is listed in Table 2.

Table 2. Equipment used by the contractor.

Equipment	Model and Capacity	Performance
Personal pumps	Gilair 5	Used to monitor worker exposure
Pump calibration units	Gilian	Used to calibrate personal pumps
Geo tarp	Sized to fit containment	Used in the containment structure
Thermal blankets	Tillman 1000°F blankets	Used in the containment structure
Geo booms	4 in. diameter	Can be deployed on land or water in compliance with emergency contingency plan
PM10 monitors	Gaseby Anderson GMH model	Used to monitor particulate matter smaller than 10 microns
TSP monitors	Gaseby Anderson GMH model	Used to monitor total suspended particles
HEPA VAC	HEPA filters	Used to clean up containment and is used in conjunction with needle guns for power tool cleaning.
Air compressor	185 CFM Ingersol Rand	Used to power needle guns and job air
Needle guns	Air powered	Used to dislodge trapped glass in crevices
2 Stage filtration	15 Gal per minute	Used to filter wash water
Dust collector	ARS rated at 40,000 CFM	Used for filtration of containment air
Steel tower scaffold	5 ft X 6 ft 6 in.	
Flame spray gun	Metco Model 6P	Used to apply the molten glass powder
Powder feeder	Miller Thermal Model	Supply the glass powder to the gun
Glass waste collection hopper	Supplied by CERL	Used to collect the glass
Remelt pot furnaces	Supplied by CERL	Used to remelt the glass

2. Kaneohe Bay Hangar Door Demonstration

Sampling and analysis found that the hangar door at Marine Corps Base, Hawaii at Kaneohe Bay, HI is coated with a lead-containing primer and various top coats. This type of paint system is commonly used on hangar doors and other steel infrastructure within the DoD and the Department of Transportation (DOT) for steel structures in atmospheric exposure. The door is representative of hangars in the DoD. The site is an active hangar building for helicopter repair and maintenance. Zatorski Coating Company, Inc. (ZCC) developed a system using water mist that reduces warpage due to heat from TSV on thin cross section steel. This successful demonstration can lead to immediate implementation of the technology on hangar doors. This technology has demonstrated rapid deployment and rapid removal of paint that improves facility readiness. The TSV process has low implementation costs for small areas since there is no need for containment structures.

CERL awarded the thermal spray removal contract to the Zatorski Coatings Company, Inc. This included preparing the Contract Solicitation and Specification document as well as conducting an environmental and safety review of the contract, the bid solicitation, and contract award.

The hangar door at the Marine Corps Base was on a portion of Hangar 3, Building 103 which was undergoing rehabilitation. This provided a challenge for lead-containing paint abatement since the floor was newly refinished adjacent to the interior of the hangar door.

This demonstration was conducted at ground level without the need for scaffolding or ladders. Since this was an active hangar, permission was obtained through the Marine Corps Base, Hawaii (MCBH), Facilities Department to use the 110V power and compressed air available in the hangar. The power was routed through ground fault interrupters in accordance with the demonstration plan. The compressed air, although already at a dew point below -18 °C (0 °F) was passed through additional dryers prior to use in the TSV process. This is a standard practice in field installations for thermal spray processes. Oxygen, acetylene and propane for the TSV process was obtained through a local vendor and secured on a bottle rack during the working day. The gas location remained fixed for the duration of the demonstration. The contractor stored the gasses off the base as required by the Facilities Department, MCBH.

The powder feeder and thermal spray torch were located adjacent to the work area during TSVing. For the inside of the door, the equipment was located inside the hangar. For processing outside, the equipment was located on the outside of the hangar door. The equipment was only moved once for the demonstration. The major equipment used by the contractor appears in Table 3.

Table 3. Principal equipment used by the contractor.

Equipment	Type or Model	Purpose
Thermal spray torch	Metco 6P-II	Apply glass
Powder feeder	Miller Thermal, mechanical feeder	Feed glass to torch
HEPA vacuum cleaner	Compressed air powered	Clean area, provide vacuum for needle gun
Needle gun	Compressed air powered	Clean loose debris
Air cleaners	Metco, lobe type	Remove debris, oil, and moisture from air
Thermal blankets	High-temperature welding blankets	Contain glass and paint chips in area
Hoses	Fuel, oxygen, air and water	Power or provide utilities for equipment
Furnace	Charles A. Hones pot type furnace	Remelt glass
Personal Air Pump	Battery operated type	Monitor worker exposure
Safety Equipment	Forced-air respirators, gloves, jackets, eye protection	Personal protection for workers

IV. Performance Assessment

1. Rock Island Bridge Demonstration

Evaluation of the existing paint system was conducted by personnel from the Paint Technology Center at U.S. Army Construction Engineering Research Laboratory. This included dry film thickness and adhesion measurement. The results are contained in Figures C-1 and C-2. The measured thickness of the existing paint on the flat vertical web of the bridge girder ranged from 3.3 to 5.9 mils. The existing paint was thicker on the vertical ribs and the lower horizontal flange, ranging up to 17.8 mils. The existing paint was well adhered to the substrate. Personnel from U.S. Army CHPPM sampled the existing paint system and found it contained from 106,000 to 495,000 mg/kg Pb. The vitrified paint contained up to 48,200 mg/kg Pb.

During the initial application of TSV, it was noted by the operator that the vertical web of the beam was warping. The application of TSV was immediately stopped and the degree of warping was measured and found to range up to 3/8 inch. A structural engineer from the Corps of Engineers Rock Island District inspected the beam and concluded that the warping did not adversely impact the structural integrity of the beam or of the bridge. The warping was due to excess heat applied to the vertical web of the beam during preheating of the substrate. The steel temperature on the back of a vertical web of the bridge was measured with a thermal couple during application of the TSV to the front side of the vertical web and is shown in Figure C-3 and C-4. The maximum temperature recorded for the two locations was 273 °C (523 °F) and 322 °C (611 °F). The issue of temperature control is only an issue with thin cross section substrates that are less than 0.200 inches thick. The vertical webs are relatively thin, less than ½ inch thick, and are fastened into place by rivets at the vertical supports between panels. When the web was heated with the preheat torch, the resulting thermal expansion of the web, which is constrained by the fasteners, could not be relieved except by warping. The TSV procedure was modified to eliminate the use of a separate torch to preheat the substrate. The thermal spray torch was used in a more controlled manner to preheat the substrate and the amount of warping was minimized. The temperature for these substrates can also be controlled by the use of forced air or wet forced air from the onsite compressors. There is limited cost associated with this control method. For each 100 sq ft, the time to set up a forced air cooling system is less than 15 minutes. At $24/hr, the cost is $6.00 per 100 sq ft or $0.06 per sq ft. This is included in the revised labor cost for application of TSV, Section 6.1

During a previous proof of principle field test of TSV at the Triborough Bridge in New York City there was no warping of the beams. The beams on the Triborough Bridge differed from the Rock Island Bridge in that they were a one piece design that did not have separate constrained vertical web panels. The steel on the Triborough bridge was also thicker, greater than ¾ inch,

such that a separate preheat torch was necessary to supply sufficient heat to the substrate for the glass to stick to the substrate and react with the lead-containing paint.

TSV met the principal performance criteria of providing surface preparation for repainting. Following application of TSV, the surface was inspected by personnel from the Paint Technology Center at U.S. Army Construction Engineering Research Laboratory and was found to met the requirements of the Steel Structures Painting Council (SSPC) SP1 and SP3 required in the contract specification and was suitable for repainting with a surface tolerant coating system. The surface profile was measured using ASTM D 4417 and found to range from 2.0 to 3.0 mils, Figures C-5 and C-6.

The first paint coat was a Sherwin Williams industrial coating SSPC 25 red primer. The top coat was a Sherwin Williams VOC complying industrial enamel No. 2.16. This is a medium oil, alkyd, all purpose enamel designed for new construction and maintenance work and provides performance comparable to products formulated to Federal Specification TT-E-489. Temperature and relative humidity were measured prior to painting. The temperature of the substrate was more than 5°F higher than the dew point and the relative humidity was below 80% before painting commenced. The contract specification required a spread rate of 500 sq ft per gallon. One gallon of the primer and one and half gallons of paint were used to apply the one coat of the primer and two top coats over the 180 sq ft area of the demonstration. The measured thickness of the dried primer ranged from 1.7 to 3.4 mils and was on average 3.0 mils, Figure C-7, Table C-3, Figure C-8, and Table C-4. The measured thickness of the completed coating system primer plus top coats ranged from 5.4 to 8.4 mils and was on average 6.9 mils, Figures C-9 and C-10, and Tables C-5 and C-6.

X-ray fluorescence analysis found the lead concentration in areas adjacent to the demonstration with intact original coating ranged from 4.7 to 5.8 mg/cm^2, Figure C-11 and Table C-7. In areas on which the thermal spray vitrification was demonstrated, the measured lead concentration was found to range from 1.0 to 2.1 mg/cm^2, Figures C-12 and Figure C-8. As with most other paint-removal processes, such as chemical removal, some residual lead was present on the surface. The aim of this demonstration was to reduce the concentration of lead on the surface to less than 1.0 mg/cm^2. The retention of lead on the steel surface is a function of the experience of the applicator, the original amount of lead present, and the number of applications of TSV utilized. During the demonstration, two applications of TSV were used. One or two additional applications of the process would be expected to further reduce the residual concentration of lead on the substrate to below 1.0 mg/cm^2. Experience with the technology also reduces the amount of lead remaining on the surface. The workers in this test had less than 2 days of experience by the end of the test. With a week of on-job experience, the amount of residual lead should also be reduced as the applicators become more proficient. The lead retention does not appear, with the data in hand, to be a function of the lead paint type or age. During any future paint removal from the

area, proper protection and testing of the workers would be required to verify that worker exposure to any residual lead on the surface was below the regulatory requirements applicable at that time.

Analysis of the air in the worker breathing zone was conducted by CHPPM during the thermal spray vitrification demonstration on the Viaduct Bridge at the Rock Island Arsenal. Monitoring for metals, dust and silica included the following: aluminum, antimony, arsenic, barium, chromium, cadmium, calcium, cobalt, copper, respirable dust, iron, lead, magnesium, mercury, molybdenum, nickel, crystalline silica, tin, titanium, vanadium, zinc, and zirconium. The results of 493 samples of metals, dust, and silica were reported by CHPPM. Monitoring for combustion products included the following compounds: benzene, carbon monoxide, nitric oxide, nitrogen dioxide, oxides of nitrogen, oxygen, ozone, and sulfur dioxide. The results of 55 air samples for combustion products were reported. The results are presented in a supplementary report prepared by CHPPM, tilted "Phase 2, Industrial Hygiene Study, No. 55-ML-5090-98 Lead Paint Vitrification Research Demonstration Project, Rock Island Arsenal, Rock Island, Illinois, 2-4 September 1997" (Ref. 6).

CHPPM concluded that the potential to exceed current airborne occupational health standards for some chemicals [Pb, respirable and total dust, (additive effects of CO + NO), and NO_2] is high whenever vitrification will occur in areas where the plume is inhibited. This would include enclosed/containment structures (such as at the Rock Island bridge demonstration) and in unenclosed areas such as under a bridge or where there is a roof/ceiling above the plume, etc. The hazard will be less whenever vitrification occurs in areas where the plume is uninhibited (e.g., on the outside of a bridge, as in the proof of principle field test at the Triborough Bridge) or a heat shield is used. The hazard will be least where the plume is uninhibited and a heat shield is not used (e.g., on the outside of a bridge, as in the field test at the Triborough Bridge). The Pb concentrations were much higher during the demonstration on the Rock Island Bridge as compared to the proof of principle field test at the Triborough Bridge. This was primarily because the vitrification occurred in an enclosed area. Although ventilated at a high exchange rate, the plume was inhibited, the Pb concentration in the paint was also about 3-times greater, and no heat shield was used. At the Rock Island Bridge Demonstration, the contractor provided full containment in accordance with SSPC 6, Class 1C, shown in Figure B-6. The total containment was found to inhabit the plume and contribute to dead air space that allowed airborne materials to concentrate. Even though there was positive pressure air flow through the containment structure, there were spaces that collected air borne contaminants because the flow did not sweep these areas out.

CHPPM also concluded that there is the potential to exceed current airborne occupational health standards for Pb and possibly CO when working around the glass remelter. Installing local exhaust ventilation, such as a chimney, at the glass remelter would help capture metal fumes and

combustion gases and reduce worker exposure, perhaps reducing the level of respiratory protection required or eliminating the need altogether.

Based on these conclusions, CHPPM made recommendations for respirator protection of the workers during the application of TSV for each of the following conditions:

(a) Enclosed containment structures or where the plume is inhibited by an overhead ceiling or roof. As a minimum, workers should wear a National Institute for Occupational Safety and Health (NIOSH) certified pressure-demand or positive-pressure supplied-air respirator equipped with either a one-half or full-face piece when the process is either enclosed in a containment structure (e.g., enclosure such as in the Rock Island Arsenal bridge demonstration) or where the plume is inhibited (i.e., roof/ceiling above the plume, such as under a bridge, etc.). Note that these recommendations apply to all cases where the plume is inhibited, even when the process is not enclosed. When the plume is not able to escape freely it will return into the face of the worker in concentrations that require a higher level of worker protection than paragraphs (b) and (c) below.

(b) Well-ventilated outdoor areas where plume dissipation is uninhibited and heat shield is NOT used. As a minimum, workers should wear a NIOSH-certified full-face air-purifying respirator equipped with HEPA filters in well-ventilated outdoor areas where plume dissipation is uninhibited (e.g., on outer portion of a bridge, as in the proof of principle field test at Triborough Bridge, where there is no overhead ceiling or roof) and a heat shield is NOT used. Nitric oxide, NO_2, and CO should be monitored closely and the level of respiratory protection increased to that described in paragraph 5.1.2.a should exposures exceed the Threshold Limit Value (TLV) or Personal Exposure Limit (PEL).

(c) Well-ventilated outdoor areas where plume dissipation is uninhibited and a heat shield is used. As a minimum, workers should wear a NIOSH-certified half-face air-purifying respirator equipped with HEPA filters when in well-ventilated outdoor areas where plume dissipation is uninhibited (e.g., on outer portion of a bridge, as in proof of principle field test at the Triborough Bridge, where there is no overhead ceiling or roof) and a heat shield is used.

(d) During remelting of the glass: As a minimum, workers should wear a NIOSH-certified half-face air-purifying respirator equipped with HEPA filters when conducting remelt operations in well-ventilated outdoor areas where plume dissipation is uninhibited. Should the glass remelter be equipped with adequate local exhaust ventilation, the level of respiratory protection required may possibly be lessened depending upon monitoring results.

The remelted waste successfully met EPA regulatory guidelines for leachate (using TCLP), but required a total remelt time of 5 hours. The initial remelt was performed for 1 hour (according to

the routine procedure) and resulted in a heterogeneous mixture. Some of the samples from the initial 1 hour remelt met EPA regulatory guidelines, but other samples did not (Table 4).

Table 4. Characterization of the remelted waste.

Sample Collected By	Total Remelt Time	TCLP Result for Pb (ppm)	TCLP Limit for Pb (ppm)	Comment
CHPPM	1 hr	2.9	5.0	Pass
CHPPM	1 hr	12.0	5.0	Fail
CERL	1 hr	2.3	5.0	Pass
Contractor	1 hr	320	5.0	Fail
Contractor	1 hr	360	5.0	Fail
CERL	2 hr	58	5.0	Fail
CERL	2 hr	57	5.0	Fail
CERL	5 hr	2.0	5.0	Pass
CERL	5 hr	2.4	5.0	Pass

2. Kaneohe Bay Hangar Door Demonstration

TSV was used on a total of 171 sq ft of painted area on the hangar door. This consisted of the flat outside door surface and flat surface and beams on the interior of the door.

The existing paint consisted of several layers of paint from various overcoats. This film thickness was analyzed in accordance to the procedures outlined in Section 4 above. The dry film thickness on the exterior door skin ranged from 17.8 to 23.9 mils with an average of 20.76 mils. The thickness on the interior door skin ranged from 4.9 to 8.8 mils with an average of 7.1 mils. The paint on the frame surfaces ranged from 3.2 to 17.3 mils with an average of 10.27 mils. The paint system on the exterior skin contained an average of 2.57 mg/cm^2 of lead measured by an X-ray fluorescence instrument. The paint system on the interior skin contained an average of 5.5 mg/cm^2 of lead. The paint of the frame members contained an average of 12.89 mg/cm^2 of lead.

The interior of the door was processed first. The water mist system was setup on the outside of the door. The mist was adjusted to allow the interior of the door to achieve the processing temperature of over 204 °C (400 °F) while the exterior of the door was maintained at less than 100 °C (212 °F). The setup time for the water mist system was less than 15 minutes for each side of the door. The vertical sheet metal which was a thickness of approximately 3.63-mm (0.143 inches) had minimal warping which disappeared upon cooling. The beams did not warp during processing and therefore did not require any mist cooling. During interior processing, the exte-

rior paint softened and debonded. Most of this paint could be removed with a paint scraper. This removed paint was processed during the remelting phase of TSV.

Two applications of TSV were used on most areas of the interior of the door. On the top of the beams where the paint was thicker, three applications of TSV were used. Only one application of TSV was used on the exterior of the door.

For hangar doors, a separate torch is not required to pre-heat substrates because the substrate is relatively thin. The thermal spray torch provided all the heat necessary to perform TSV.

Several of the bolts on the bottom of the door that were heavily corroded failed and fell off the door during the heating and cooling during the TSV. This failure was anticipated during the initial inspection of the door. After TSV processing, new bolts were installed.

The surface was cleaned with a needle gun to remove any loose debris on the surface. This operation was performed in less than 1 hour for the TSV-processed area.

The surface was primed with Rustbond Penetrating Sealer SG from Carboline Corp., St. Louis, MO. The top coat for the interior was Carbomastic 15 Low Odor and the top coat for the exterior was Carboline 3359, a water-borne acrylic. The top coat choice was recommended by the local Carboline representative and approved by CERL. The contractor followed the manufacturer's recommendations for mixing and applying the paint. During paint application, the temperature was above the minimum and humidity was below the maximum manufacturer's recommendations.

The personal air samples and area samples were analyzed for lead according to NIOSH Method 7300. The results of the testing were time-weighted averages for eight hour exposures. The lead level in the personal air sample from the workers performing TSV was 50.9 micrograms/m^3. The lead level in the personal air sample for the person performing the needle gun operation was <20.4 micrograms/m^3. The level of lead behind the TSV operator, inside the controlled area was <2.1 micrograms/m^3. The lead concentration 20 feet downwind from the TSV process directly outside the control area was 1.11 micrograms/m^3. For reference, the personal exposure limit (PEL) for lead is 50 micrograms/m^3.

The respirable dust level was measured using the NIOSH method 600. The respirable dust for the operator performing TSV was 0.4 mg/m^3.

The lead concentration on the interior skin after TSV processing and before needle gun cleaning averaged 1.465 mg/cm^2. The lead concentration on the framing after TSV and before needle gun cleaning averaged 2.87 mg/cm^2. The lead concentration on the exterior skin after needle gun

cleaning averaged 1.05 mg/cm^2. The lead concentration on the interior skin after needle gun cleaning averaged 1.14 mg/cm^2. The lead concentration on the framing after needle gun cleaning averaged 2.44 mg/cm^2. The complete data for these readings are located in Appendix D at Figures D-3 and D-4.

The glass was remelted in a pot-type furnace according to previously developed procedures. This resulted in a waste that did not pass regulatory limit of less than 5 ppm of lead as analyzed by the TCLP test. The original procedure was:

1. Add the waste from TSV to the furnace until full.
2. Stir every 15 minutes.
3. Heat the furnace to at least 800 °C (1470 °F) and maintain for 4 hours.
4. Remove the molten glass from the container by pouring or by use of utensils into water.
5. As soon as the danger of scalding is past, remove the glass from the water using separate utensils to prevent contamination.

The resulting waste from this procedure had TCLP values from 16 to 170 ppm of lead, above the regulatory limit for nonhazardous waste.

This procedure was modified to allow more time for the lead to vitrify into the glass structure. The final process involved the high temperature furnace, stirrers, safety equipment and water bath. The procedure was:

1. Add the waste from the TSV process to the furnace until full.
2. Stir every 15 minutes.
3. Heat the furnace to at least 800 °C (1470 °F) and maintain for 1 hour.
4. Shut off the heat and furnace cool the waste overnight.
5. After cooling, reheat the furnace to at least 800 °C (1470 °F) and maintain for 1 hour.
6. Remove the molten glass from the container by pouring or by use of utensils into water.
7. As soon as the danger of scalding is past, remove the glass from the water using separate utensils to prevent contamination.

The resulting waste had TCLP values ranging from 0.62 to 3.0 ppm of lead.

V. Cost Assessment

1. Rock Island Bridge Demonstration

Based on the Rock Island demonstration, the expected operational cost of TSV for a 1000 sq ft area of a bridge are shown in Table 5. The labor rates used were the prevailing wage rates determined by the U.S. Department of Labor for Rock Island County, IL, which were included in the Construction Solicitation and Specification. The prevailing hourly wage rates, including salary and fringe benefits, were the following: Carpenter – $27.43; Painter – $24.62; and Laborer – $22.73.

For the Rock Island TSV demonstration, the site foreman and thermal spray applicators were painters paid at an hourly rate of $24.62. Production rates observed during the demonstration were 30 sq ft per hour. This was for workers with no previous experience who applied the process in two cycles. It is expected that with additional experience, the workers would be able to execute three applications of TSV at rate of 30 sq ft per hour. Three applications would be required to reduce the residual lead on the substrate to levels below 1.0 mg/cm^2. For a 1000 sq ft area, the amount of labor required for TSV was estimated at 24 hours by an applicator and 40 hours by a foreman. This includes the labor associated with the use of a water mist to reduce the temperature of the steel during TSV. The labor required to remelt the glass is estimated to be 8 hours if a larger-capacity portable furnace is used.

During the demonstration on a 180 sq ft area, approximately 90 lb of glass powder was used, or 1/2 lb per sq ft. With additional applications of TSV required to reduce residual lead, it is conservatively estimated that 1 lb of glass would be required per sq ft. Seiler Pollution Control Systems, Inc., of Dublin, OH, has estimated that new glass powder could be produced by recycling the glass from the TSV process at a cost of $0.50 per lb. Therefore, the total cost of the glass powder would be $500 per 1000 sq ft. Utility costs such as compressed gases, fuel for the remelter, air compressor and power generators are estimated at $200. Including miscellaneous materials, the total material costs are estimated at $800 per 1,000 sq ft. The cost of the worker health monitoring is estimated at $250 per worker, including the cost associated with initial monitoring of the workers at a new job site. The cost of environmental monitoring is estimated at $150 per 1000 sq ft of treated surface. Waste transportation costs were estimated at $100 for this job. Disposal costs are estimated and include nonhazardous glass generated in the remelter, $25, and a very small quantity of hazardous waste consisting of oily rags and paint waste from the power tool cleaning, $100.

The final operational costs for the TSV process were projected to be between $5.30 and $9.37 per sq ft, based on a paint-removal area of 1000 sq ft and a paint removal rate of 300 to 600 mils

- ft^2/hr. When TSV is conducted with other related maintenance and repair (M&R) activities, the costs associated with construction of temporary scaffolding and demobilization would be shared as part of the other onsite work. Additional cost saving would also be expected through the sharing of utilities and bulk purchases of gases and fuels. Therefore, the projected costs for the deleading could be reduced to as low as $3.50 per sq ft. However, depending on the complexity of the structure (truss bridges are more expensive that girder bridges) and the location of the job site (over water), the cost may be higher than average. The average cost of the TSV process is estimated at about $5.00 per sq ft, with a possible range from $3.50 to $9.50 per sq ft.

Table 5. Estimated operation cost for TSV (1000 sq ft).

Startup		**Operation and Maintenance (Surface Preparation and Repainting)**		**Demobilization**	
Activity	**$ [h]**	**Activity**	**$ [h]**	**Activity**	**$ [h]**
Rate (Carpenter)	27.43	Rate (Painter)	24.62	Rate (Laborer)	22.73
Hours (Carpenter)	[8]	Hours (Painter)	[34-68]	Hours	[8]
Rate (Foreman)	24.62	Rate (Laborer for remelt)	22.73	Rate (Foreman)	27.43
Hours (Foreman)	[8]	Hours (Laborer for remelt)	[8-32]	Hours (Foreman)	[8]
		Rate (Foreman)	24.62		
		Hours (Foreman)	[40-80]		
Labor Subtotal	**416**	**Labor Subtotal**	**2661-4050**	**Labor Subtotal**	**401**
Materials for scaffolding and containment	100	Glass powder	500 - 1500		
		Utilities (including, compressed gases, fuel for remelt, air compressor and power generators)	200-400		
		Misc. Materials	100		
Materials Subtotal	**100**	**Materials Subtotal**	**800-2000**		
		Equipment depreciation (10 yr, 60%)	10		
		Consumables	350		
		Worker protection and health monitoring	250		
		Environmental monitoring	150		
		Waste transportation	100		
		Waste disposal (nonhazardous)	25-50		
		Waste disposal (hazardous)	100		
Overhead/Profit (10%)	52	Overhead/Profit	390-760	Overhead/Profit	40
Category Total	568		4291-8365		441
Total					**5300-9374**
Cost per sq ft					**$5.30-9.37**

The Federal Highway Administration and the National Transportation Research Board have conducted studies on the cost of removing lead-based paint from highway bridges (Ref. 10, 11). The costs of various paint-removal technologies are shown in Table 6. As stated above, the projected cost for the TSV process ranges from \$3.50 to \$9.50 per sq ft, with an average cost projected at less than \$5.00 per sq ft. Table 6 illustrates that this range is lower than the costs of other technologies, which range from \$7.00 to \$13.00 per sq ft. Based on discussions with the Army Corps of Engineers district engineers, the cost of lead paint removal using existing technologies was more than \$20 per sq ft for Lock and Dam No. 13 on the Mississippi River.

Table 6. Costs for various lead-based paint-removal processes.

Technology	Range \$/sq ft	Average \$/sq ft
Thermal Spray Vitrification (Projected)	3.50 - 9.50	5.00
Abrasive Blasting	5.00 - 18.00	8.00
Wet Abrasive Blasting	5.00 - 20.00	12.00
Vacuum Blasting	4.00 - 20.00	10.00
Water Blasting	4.00 - 20.00	13.00
Water Blasting with Abrasive Injection	4.00 - 19.00	9.00
Power Tool Cleaning To Bare Metal	5.00 - 15.00	7.00

2. Kaneohe Bay Hangar Door Demonstration

The expected costs of TSV for areas of greater than 1000 sq ft are shown in Table 2. These estimates are valid for areas of up to 6000 sq ft. The data were developed from this hangar door demonstration and previous work. The assumed labor rates are \$25.00 for a painter/foreman and \$21.00 for a laborer. The observed production rates during this hangar door demonstration ranged from 20 sq ft/hr to more than 48 sq ft/hr with two TSV applications. For areas over 1000 sq ft the estimated production rate for three TSV applications is 35 sq ft/hr. The labor to remelt the glass is estimated at 8 hours using a production-type furnace.

During this demonstration, 171 sq ft of the hangar door were treated by TSV. Less than 55 lb of glass were used during paint removal, but additional glass was used during the remelt portion of the process. The total amount of glass used during this demonstration is conservatively estimated at 0.75 lb/sq ft. For larger areas, the cost of the glass can be as low as \$0.50/lb. This estimate is based on using a combination of virgin glass and recycled glass. Zatorski Coating Company, Inc., has demonstrated the ability to reduce the recycled glass to a usable consistency and grain size for TSV by ball milling and sieving.

The cost analysis shown in Table 7 for two TSV applications results in a cost per sq ft of between \$3.52 and \$3.89 based on paint removal rates of 700 to 1000 mils - ft^2/hr. The cost per sq ft can

range from this amount up to $9.50, depending on the complexity of the surfaces. The more complex the surface, the more time and glass must be used to remove the paint.

Table 7. Cost analysis for the TSV demonstration at Kaneohe Bay, HI.

Startup		**Operation and Maintenance (Surface Preparation and Repainting)**		**Demobilization**	
Activity	**$/hr**	**Activity**	**$/hr.**	**Activity**	**$/hr.**
Rate (Foreman)	$25	Rate (Foreman)	$25	Rate (Foreman)	$25
Hours	8	Hours	15 - 31	Hours	8
Rate (Laborer)	$21	Rate (Laborer)	$21	Rate (Laborer)	$21
Hours	8	Hours	6 - 8	Hours	8
		Rate (Foreman) for remelt	$25		
		Hours	8		
Labor Subtotal	**$368**		**$801-1143**		**$368**
Materials for containment of glass	$100	Glass Powder	$500		
		Utilities (compressed gasses, fuel and power)	$200		
		Misc. Materials	$100		
Materials Subtotal	**$100**		**$800**		
		Consumables	$175		
		Equipment Depriciation (10 yr, 60%)	$10		
		Worker protection, environmental and health monitoring	$250		
		Waste transportation and disposal (nonhazardous)	$125		
		Waste disposal (hazardous)	$200		
Overhead/Profit (10%)$	47		$236 - 270		$37
Category total	$515		$2597-2973		$405
Total					**$3517-3893**
Cost/sq. ft.					**$3.52 - 3.89**

3. Equipment Costs

The TSV system equipment, including spray gun, powder feeder, furnace, and related hardware costs approximately $5000 new. The expected service life for this equipment is 7 years. Expendable parts and supplies are expected to cost between $300 and $500 per year.

VI. Implementation Issues

A. Cost Observations

There are several factors that influence the cost and performance of TSV. The condition and thickness of the paint determines the amount of preheating and the number of glass layers that must be applied to remove all the paint. In field trials, operators can remove paint with a thickness of 0.25 to 0.64 mm (0.010 to 0.025 in.) in two applications of glass at a rate of 35 sq ft/hr. Additional experience should enable operators to complete three applications of glass at a rate of 35 sq ft/hr. The complexity of the structure also negatively influences the productivity of the process. Structures with excessive bends, corners, crevices and recessed areas are more difficult to access and may require additional time for final cleanup before repainting.

B. Performance Observations

For lead-containing paint abatement, TSV reduces the amount of hazardous lead dust to levels that permit the process to be performed without special containment. Other processes such as abrasive blasting require containment structures that cost several dollars per sq ft. The exact cost depends on the size of the structure. A containment structure for abrasive blasting several hundred sq ft costs from $1000 to $2500. Protection for the workers is also reduced since the exposure levels for the TSV process is less than for other processes, such as abrasive blasting.

The waste from the process is substantially less than with other processes and this waste is nonhazardous. TSV produces approximately one-half to three-quarters of a pound of nonhazardous waste for each sq ft of lead-containing paint removed. In comparison, abrasive blasting produces approximately seven to ten pounds of hazardous waste for each sq ft. Chemical strippers are slow and produce a hazardous liquid waste, including the rinse water.

TSV produces a surface that needs little additional preparation for painting. This demonstration utilized a needle gun to remove any loosely adhered glass materials from the surface.

The nonhazardous waste can be recycled for several uses. The contractor for this demonstration has demonstrated recycling the glass both as an abrasive blast media in the shop and as sprayable glass for TSV.

This technology has the ability to be employed for small lead-containing abatement jobs with quick setup and low setup costs. This is useful for highway expansion joints, bridge bearing areas and small freestanding infrastructure items such as fire hydrants.

Seiler Pollution Control Systems, Inc., is commercializing a high-temperature vitrification system that converts hazardous waste into a nonhazardous glass-ceramic material, metal oxides, and salts. The system uses the waste feedstock to produce commercial glass or ceramic products such as abrasives, construction materials (concrete mix aggregate), or refractory insulating materials. Seiler has expressed an interest in recycling the glass slag from the TSV process to produce new powder suitable for thermal spraying or other value-added products. Such reuse of the vitrified waste would reduce or eliminate waste disposal costs. Therefore, recycling the waste would make TSV more competitive by reducing feedstock costs, reducing paperwork for waste disposal, and generating income from the sale of value-added products from the recycled waste.

The demonstrated thermal spray vitrification process would be most appropriate for spot removal of lead-based paint as part of a zone painting project. In zone painting, the most corrosion-prone areas of a large structure are given a higher degree of protection. Typically for a bridge, these areas include the bearings, sections adjacent to the joints below the deck, and the lower 6 to 10 feet above the deck on the truss. In zone painting, the remainder of the bridge is either not painted at all or given a light cleaning and then overcoated. However, it is recognized that abrasive blasting using full containment may still be the most appropriate process for removing lead-based paint from an entire large structure, depending on the specific conditions.

The niche market for TSV may include surface preparation for zone painting on a large structure or small fixed structures such as fire hydrants, posts, railings, flag poles, towers, etc. For example, a potential niche application where TSV would be most appropriate, would be removal of lead-containing paint from fire hydrants. Tyndall Air Force Base (AFB), FL, has a total of the 320 fire hydrants. Inspection of a representative sample of 10% was conducted in 1998, and all of the inspected hydrants were found to be coated with lead-based paint. Current processes for lead paint removal would require that the hydrants be disassembled and then taken offsite where the lead paint would be removed by abrasive blasting or chemical stripping. TSV could be used onsite to remove lead-based paint from the hydrants without disassembling or transporting them offsite. With an estimated cost savings of $100 per hydrant, the lead-abatement savings to Tyndall AFB for 300 hydrants could be $30,000. Assuming that there are 300 major DoD installations each with 300 hydrants, the total cost savings to the DoD would be estimated at $9 million.

C. Other Significant Observations

Commonly used lead-containing paint abatement technologies include abrasive blasting inside containment, chemical strippers, closed-cycle ultra-high pressure water, and wet abrasive blasting with a chemical stabilizer (e.g., Blastox®). TSV has advantages over all these methods.

Among the advantages of TSV is the elimination of the need to build and use a containment structure. Containment structures needed for other lead-containing paint abatement methods are

expensive and time consuming to fabricate. Monitoring data collected during previous demonstrations shows that the potential is small to generate airborne lead concentrations in excess of regulatory limits when the plume from the process is inhibited. When TSV is used in an enclosed or semi-enclosed area such as between beams under a bridge, the workers should use appropriate respirators. The potential contaminants in these areas include lead dust, other fine particles from the paint and additive effects of CO, NO, and NO_2.

The waste from other methods such as abrasive blasting, chemical strippers and water blast are hazardous. Disposal of hazardous waste is costly. For example, abrasive blasting waste is estimated to cost $4 to $5/sq ft. TSV produces less waste than competing technologies and this waste is nonhazardous after onsite remelting.

TSV is limited to the removal of lead-containing paint from steel structures. This technology is not applicable to removing lead-containing paint from wood, concrete, or masonry structures because of the relatively high temperature of the process.

D. Regulatory and Other Issues

The State of Illinois, Environmental Protection Agency (IL EPA) was contacted by the Corps of Engineers Rock Island District regarding the onsite remelting of the vitrified waste during the demonstration. A copy of the memo prepared by the Corps of Engineers Rock Island District concerning the phone conversation with IL EPA is attached in Appendix E. The Corps of Engineers Rock Island District informed IL EPA about the scope and purpose of the thermal spray vitrification demonstration project as well as about previous laboratory and field test results. IL EPA, Division of Air Pollution Control, classified TSV, including the glass remelting as a repair/ construction activity and regulated it as they would a lead-containing paint cleaning operation. The IL EPA does not require air permits for paint cleaning activities (such as the project to remove lead-containing paint from a water tower at the Rock Island Arsenal). The IL EPA stated that our work did not require a permit, based on the type and amount of work. Letters were sent by the Corps of Engineers Rock Island District to IL EPA, Division of Air Pollution Control, stating that permits were not required. The contract called for the onsite remelting of the glass in order to make the waste nonhazardous and permit disposal as a special waste in an industrial landfill. Remelting the glass for a minimum of five hours resulted in a nonhazardous waste as determined by TCLP analysis.

Regulatory acceptance for the Kaneohe Bay Hangar Door Demonstration was based on successfully producing nonhazardous waste and the air quality data from the demonstration of TSV at the Rock Island Arsenal, Rock Island, IL and the data from the CHPPM report (reference 12). This information was forwarded to the appropriate agencies in Hawaii with the assistance from

the Facilities Department at the Marine Corps Base, Hawaii and the Naval Facilities Engineering Command, Pacific Division.

TSV involves both removal and subsequent remelting onsite of the glass. This is viewed by the EPA as a single operation and not a waste treatment operation. This is based on the IL EPA, Division of Air Pollution Control classifying TSV as a repair/construction activity and regulating the process as a lead-containing paint cleaning operation.

The contract required onsite melting of the glass to complete TSV and render the waste as nonhazardous as determined by the TCLP analysis. This was completed and part of the waste was disposed as nonhazardous waste in the Waimanalo Gulch Refuse Facility in Hawaii. Since the TCLP showed less than 5 ppm of lead, it was unnecessary to ship the waste to and dispose of it as a hazardous waste at a site in California or Nevada.

The remaining part of the waste was shipped to Seiler Pollution Control Systems, Inc., Columbus, OH to be tested for possible use in their recycling plant operations. Seiler produces glass grit products for non-skid paints, grit blasting, grit for roofing shingles, and other products.

E. Lessons Learned

The demonstration of the thermal spray vitrification (TSV) process was successful in achieving all of the objectives including (1) removal of lead-containing paint in the field from steel structures, (2) meeting of all applicable environmental standards, (3) meeting of all applicable worker health and occupational safety standards, (4) creation of a suitable surface for recoating the steel substrate with a surface-tolerant coating system, and (5) collection of data and estimation of production rates.

Onsite remelting of the waste required a minimum of five hours at 800 °C (1470 °F) to ensure the homogenization of the melt and full immobilization of the hazardous species in order to render the waste nonhazardous as determined by RCRA.

In future depainting of the structure, proper protection and testing of the workers would be required to verify that worker exposure to any residual lead on the surface was below the regulatory requirement.

The amount of heat applied to the substrate during the pre-heat stage of the process must be carefully monitored and controlled to avoid warping the substrate.

The production rate of TSV was estimated at 30 sq ft per hour and the cost was estimated to range from \$3.50 to \$9.50 per sq ft with an average cost of \$5.00 per sq ft.

The glass from TSV can be recycled using commercial processes that converts the waste into a nonhazardous value added glass or ceramic products such as abrasives, construction material, refractory insulating materials or new glass powder for the TSV process. Recycling this material would reduce or eliminate the disposal costs associated with the glass waste from TSV.

It is expected that the market for TSV would be a niche market including surface preparation for zone painting on a large structure, such as a bridge, or for small fixed structures such as fire hydrants, posts, railings, fence post, flag poles, towers, etc.

The demonstration of TSV was successful in meeting all of the objectives. These included demonstrating and validating the environmental advantages of TSV for the removal of lead-containing paint from a hangar door at the Marine Corps Base, Hawaii in Kaneohe Bay, Hawaii. The main environmental and technology issues documented were: (1) the number of passes required to remove the lead from the steel structures, (2) the production rate under field conditions, (3) worker exposure level, (4) verification that the glass can be classified as a nonhazardous waste after being remelted and (5) the projected costs for implementation.

When TSV is used in well-ventilated outdoor areas, the workers should use, at minimum, a NIOSH-certified half-face air-purifying respirator equipped with HEPA filters.

During remelting of glass, workers do not need to use respirators, although workers should use a NIOSH-certified half-face air-purifying respirator equipped with HEPA filters.

Onsite remelting of glass should use the new remelt procedure.

The water misting procedure is successful and should be used on thin section steel of less than 0.200 in.

Proper protection and testing of the workers should be conducted to verify that worker exposure to lead is below regulatory limits.

The production rate using the TSV process is estimated at 35 sq ft/hr and the cost ranges from $3.43/ sq ft to $10.00/sq ft depending on the complexity of the structure.

TSV at this time is best suited to niche markets where the cost of full containment structures cannot be spread over a large area. This includes zone painting for large structures, and small fixed structures such as fire hydrants, posts, highway overpass rails, fence posts, light stands, fire call boxes, etc.

F. Scale Up

The estimated surface area of steel structures at Army facilities such as water tanks, bridges, aircraft hangars, antennas, ladders, poles, railings, catwalks, metal buildings, etc. is about 118 million sq ft. The total surface area of steel structures in the DoD is estimated at 200 million sq ft. The U.S. Army Corps of Engineers also has 275 navigation locks and dams and 383 other dams with service bridges on lakes and reservoirs which have an estimated 100 million additional sq ft of steel. Most of this steel is coated with red lead oxide primer to protect it from corrosion. Over the next 20 years this steel will have to be repainted. The cost analysis, based on data collected during the demonstration, estimated the cost of thermal spray vitrification process to range from $3.50 to $12.00 per sq ft with an average cost of about $5.00 per sq ft. This is $3.00 per sq ft cheaper than the currently used abrasive blasting at an average cost of $8.00 per sq ft. If we assume that 20% of the DoD painted steel structures can use TSV, the process is applicable to 60 million sq ft of steel. Based on a benefit of $3 per sq ft, the estimated savings over the next 20 years to the DoD are $180 million.

The technology will be implemented to the user by transferring it a commercial firm that does lead paint removal such as Midwest Foundation, a small business such as Zatorski Coating Co. or some other company. Its economic viability will be determined through its success in competitively bid paint-removal projects. The Construction Solicitation and Specification prepared for the Rock Island Bridge demonstration can be used as the guidance specification for future lead-containing paint-removal projects.

The contractor who performed the Rock Island Bridge Demonstration was obtained through a competitive bid process. The Contractor, Midwest Foundation, Tremont, IL, expressed interest in bidding on future paint-removal contracts using TSV. Zatorski Coatings Co, East Hampton, CT, a small business that was contracted to conduct the training for the demonstration as well as other companies have also expressed interested in commercialization of TSV.

ZCC is actively pursuing markets in the removal of lead-containing paint on fire hydrants and small fixed structures, highway overpass railings and small power plant fixtures such as pump casings, catwalks, railings, posts, etc. The Department of Energy and Westinghouse Corp. is planning a demonstration of TSV to remove mixed hazardous and radioactive waste in air ducts at nuclear facility in Savannah River, GA. This demonstration has a planned start date of December 1998.

The technology is being actively transferred to contractors through the demonstrations on the viaduct bridge at the Rock Island Arsenal, Rock Island, IL, the hangar door at the Marine Corps Base, Hawaii at Kaneohe Bay, HI and the fire hydrants at the Tyndall AFB, FL. The summary of the Tyndall AFB demonstration is at Appendix E.

Additional Demonstrations for small components at Army installations are planned. Technology Demonstration funds have been authorized in POM (00-03).

To fully commercialize the process, scale up of the glass remelting process would be required. This would include the use of a larger size glass melter such that the vitrified glass from a day's paint removal could be remelted in one operation. The larger melter would also permit measurement and control of the melt temperature and could provide stirring of the molten glass. Such a melter may require mounting on a truck or a trailer to be deployable in the field.

Alternately, the vitrified glass could be recycled and used as feedstock to produce new glass powder or other glass or ceramic products. According to the recycling exemption of the Resource Conservation and Recovery Act, the vitrified product would not be classified as solid waste if it is used or reused as an ingredient in an industrial process to make a product (Ref. 7). Recycled products can be other glass or ceramic products. Potential uses currently under investigation by Seiler Pollution Control System Inc, Dublin, OH, include abrasive grit blasting media for blasting, buffing and polishing applications as well as roofing tile granules and architectural materials (Ref. 8). Seiler has received approval from the California Environmental Protection's Department of Toxic Substance Control (DTSC) for production of recyclable materials from three different waste feed stocks: abrasive blast media, steel mil dust, and industrial waste water treatment sludge (Ref. 9). The reuse of the vitrified product as feed material for TSV is also under investigation.

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Appendix A: Points of Contact

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Appendix B: Figures

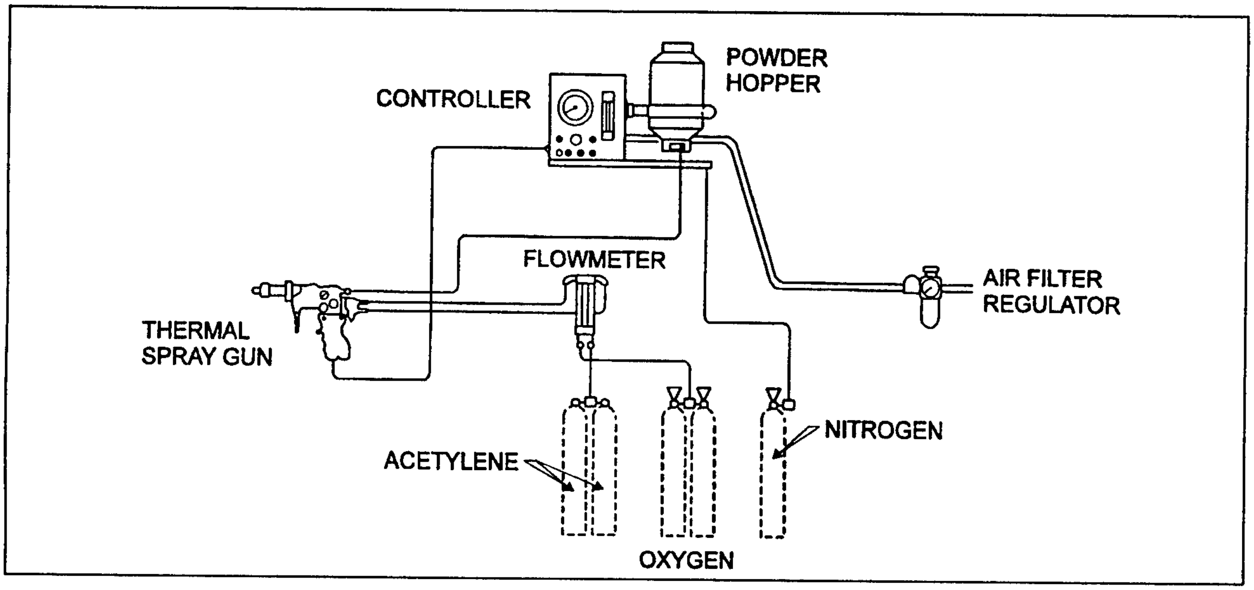

Figure B-1. Schematic of the thermal spray system.

Figure B-2. Application of TSV process to Viaduct Bridge at the Rock Island Arsenal.

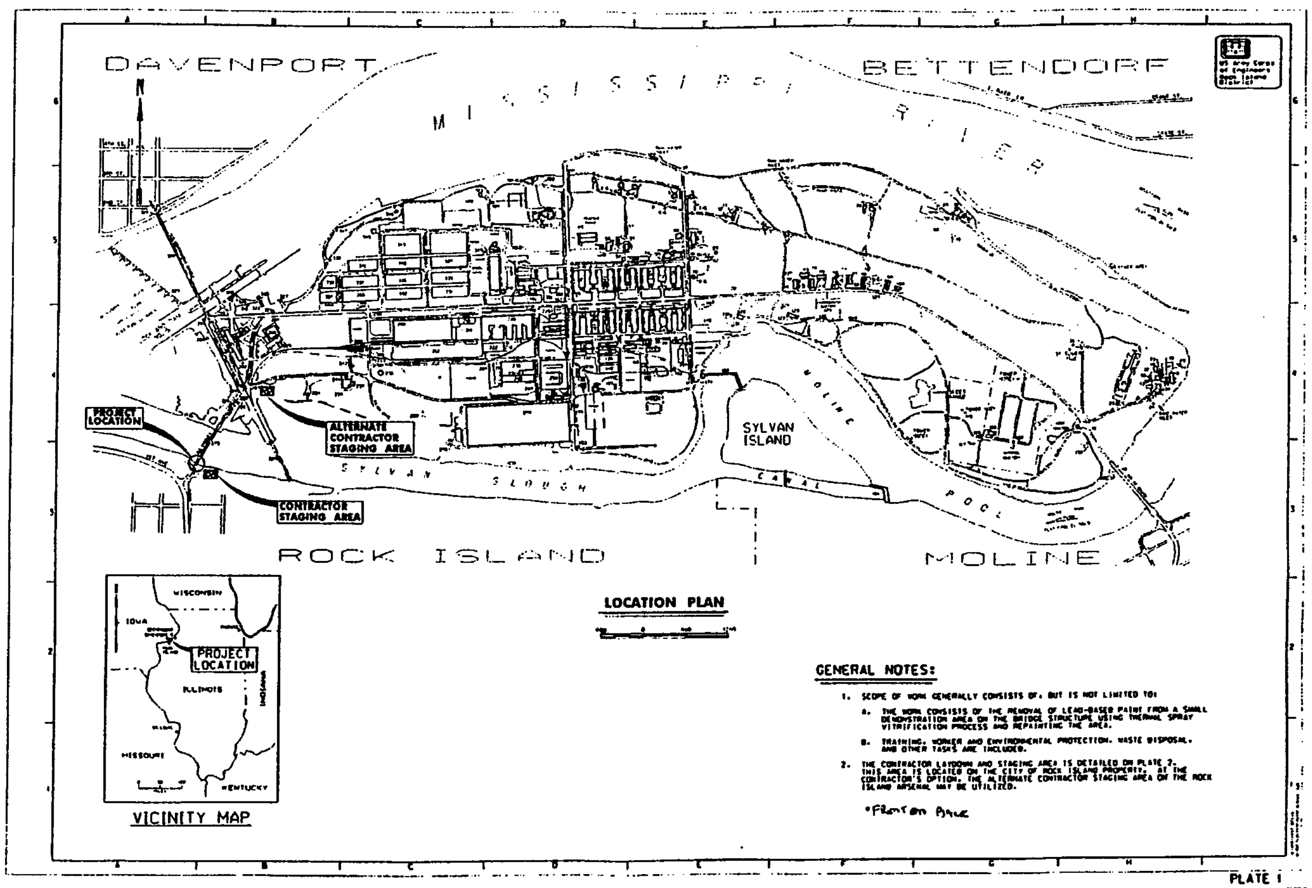

Figure B- 3. Location plan of the Rock Island Arsenal.

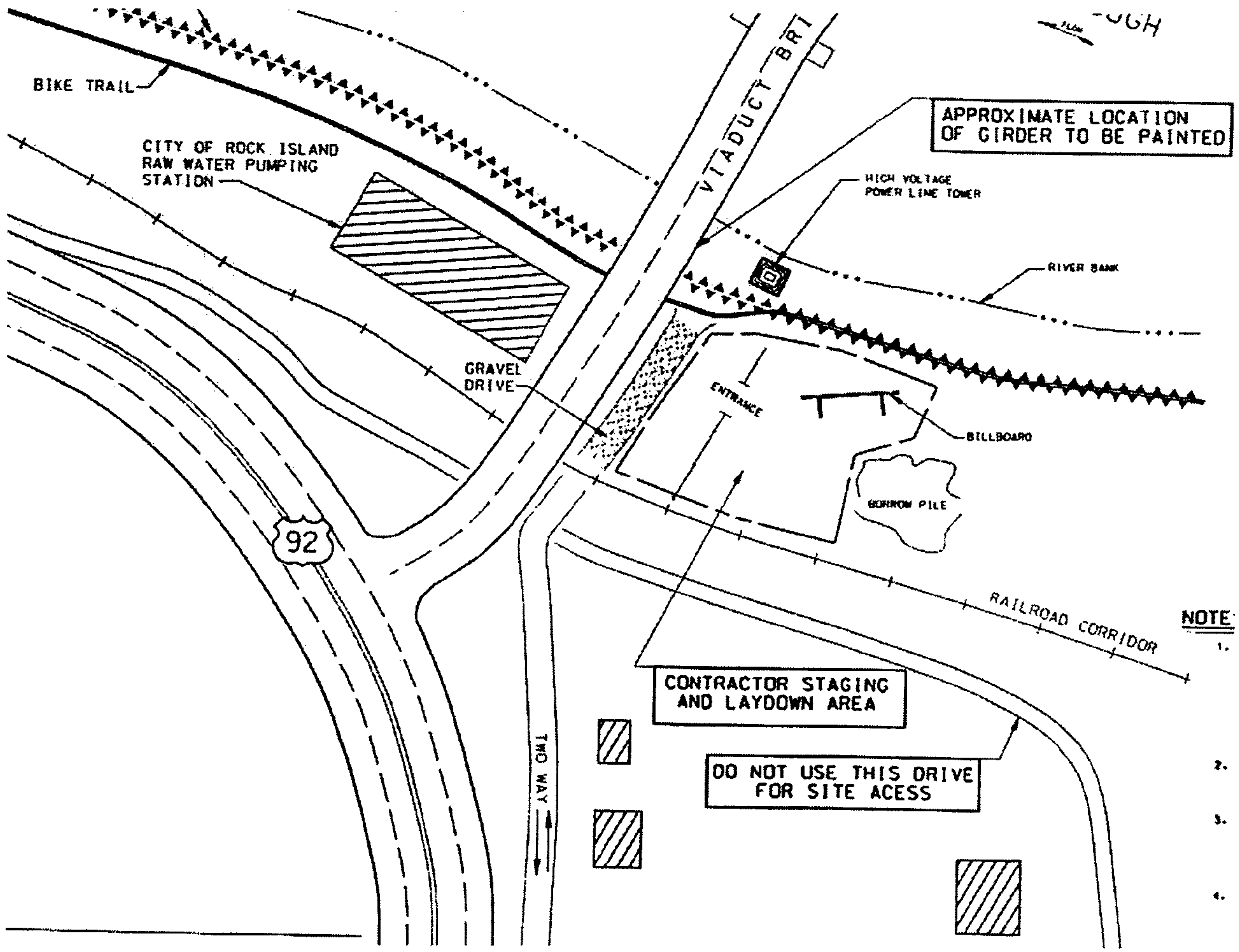

Figure B-4. Detailed location plan of the Viaduct Bridge.

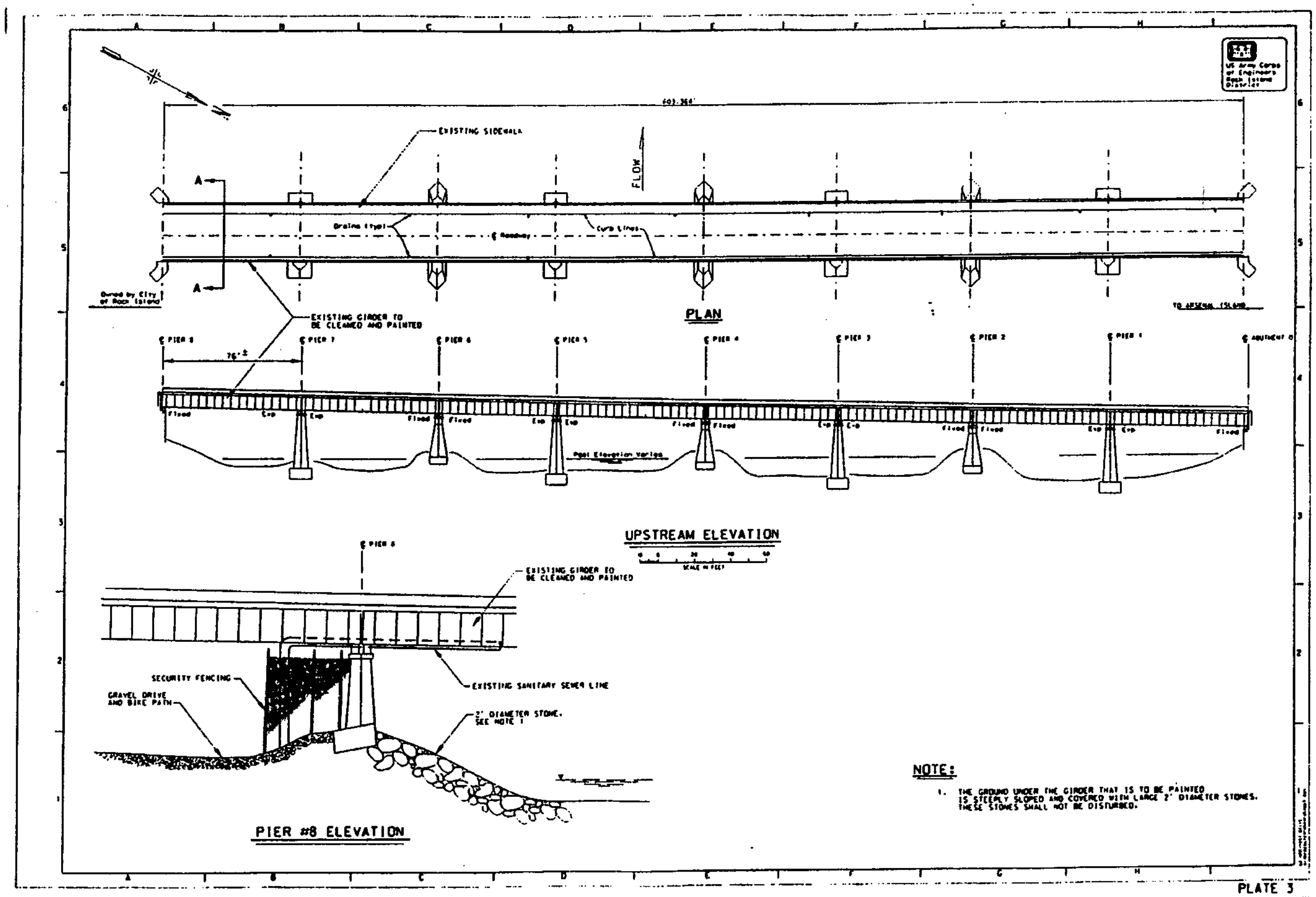

Figure B-5. Drawing of the bridge.

Figure B- 6. Containment structure built for the Rock Island Bridge demonstration.

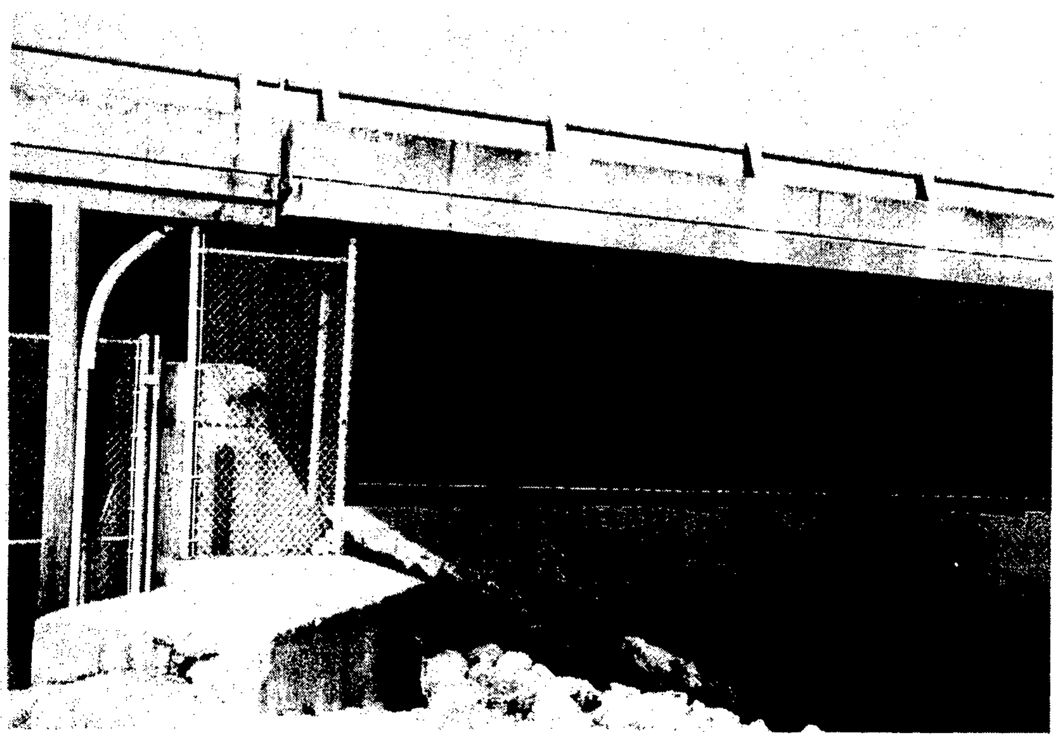

Figure B- 7. The Viaduct Bridge at the Rock Island Arsenal after the TSV demonstration.

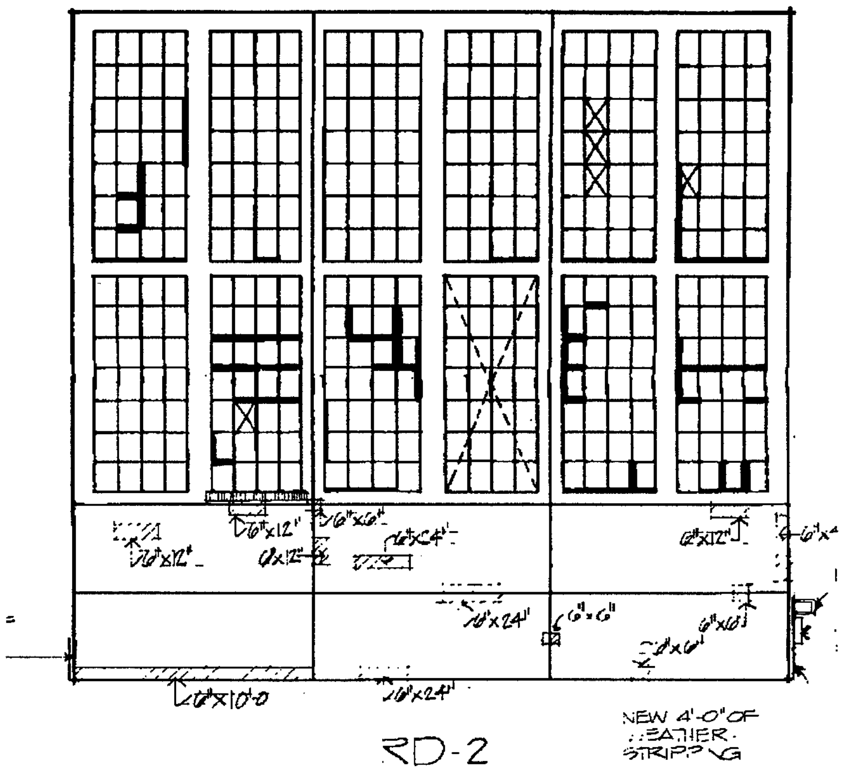

Figure B- 8. Diagram of a typical door section in Building 103.

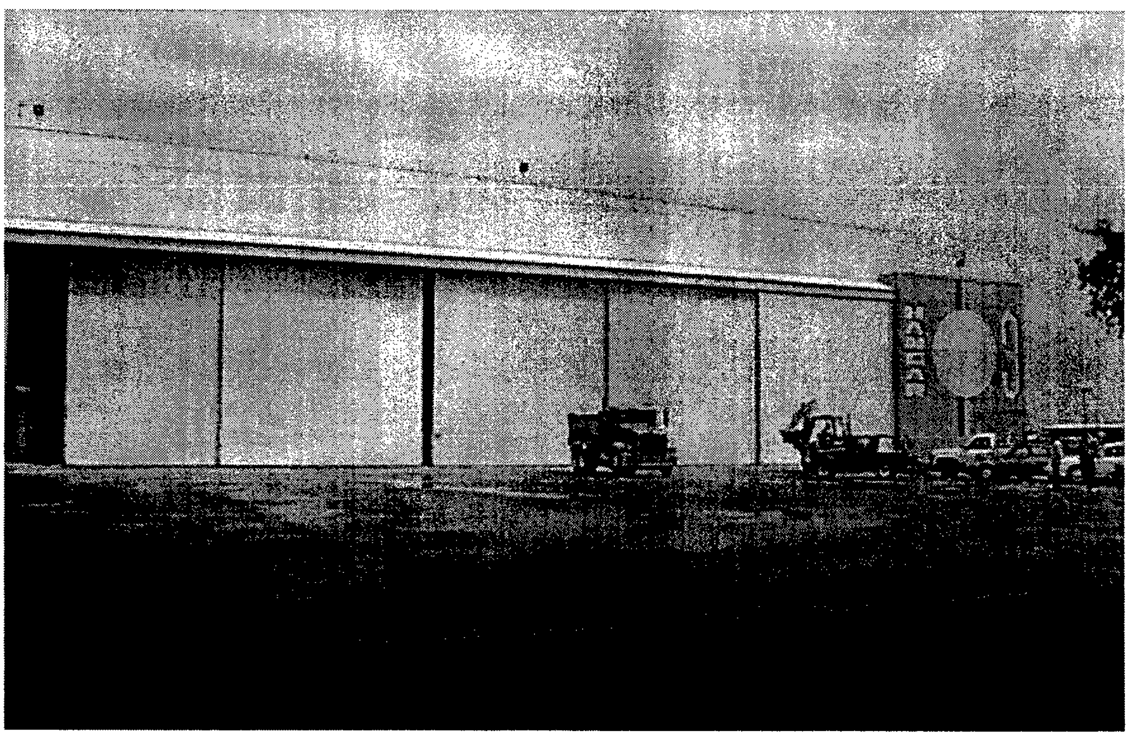

Figure B- 9. Photograph of hangar door and building exterior from southeast.

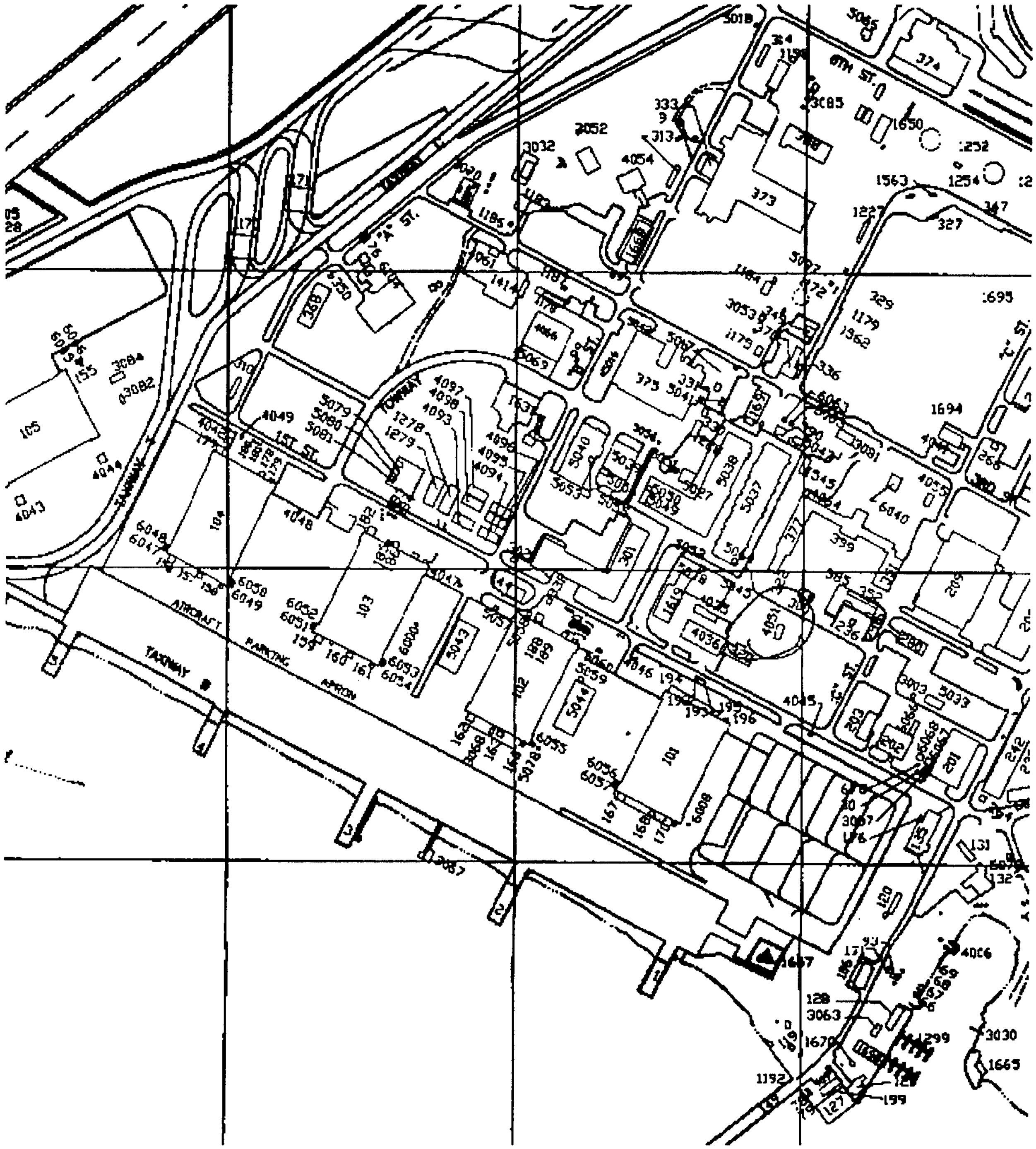

Figure B- 10. Drawing of the site layout of the Marine Corps Base Hawaii.

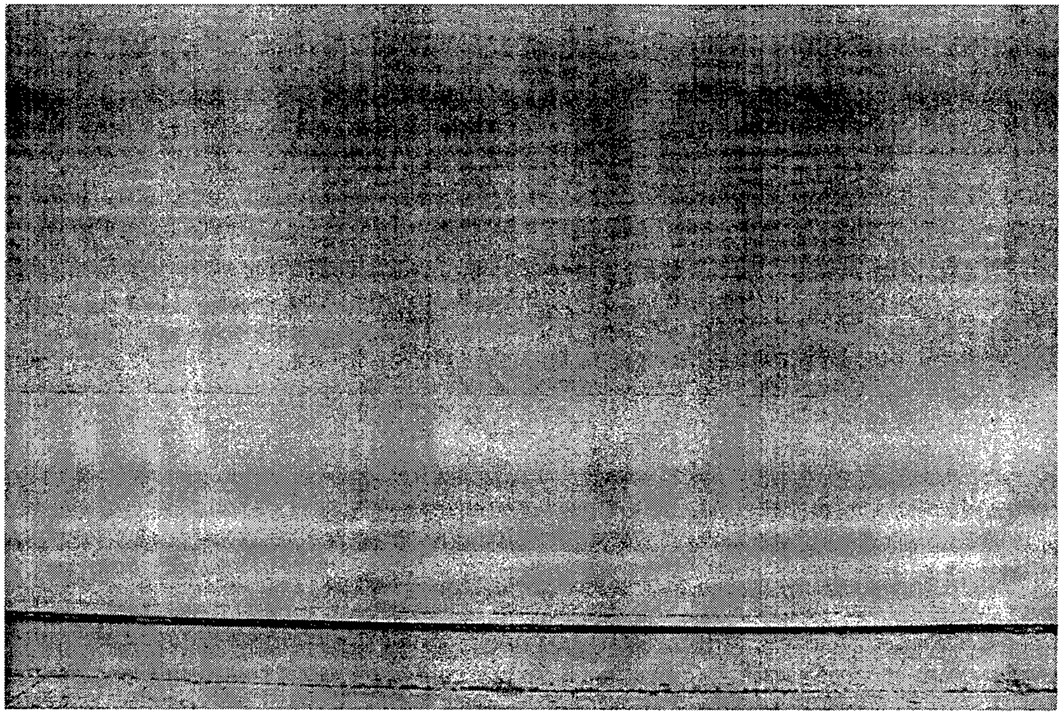

Figure B- 11. Photograph of the hangar door exterior before TSV application.

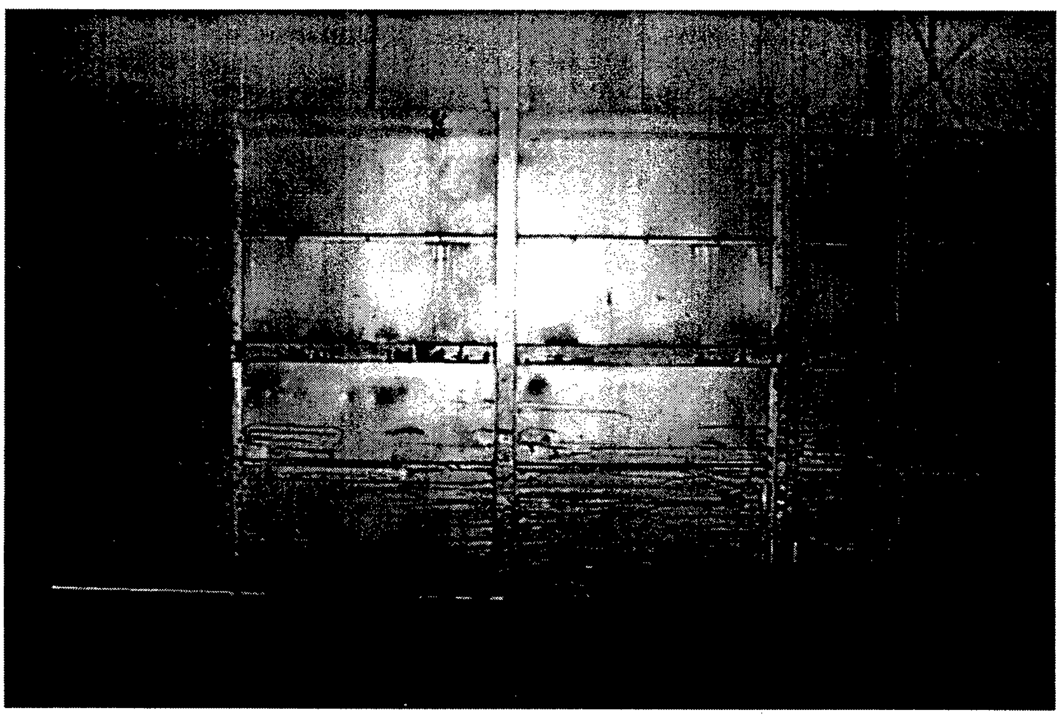

Figure B- 12. Photograph of interior of hangar door before TSV application.

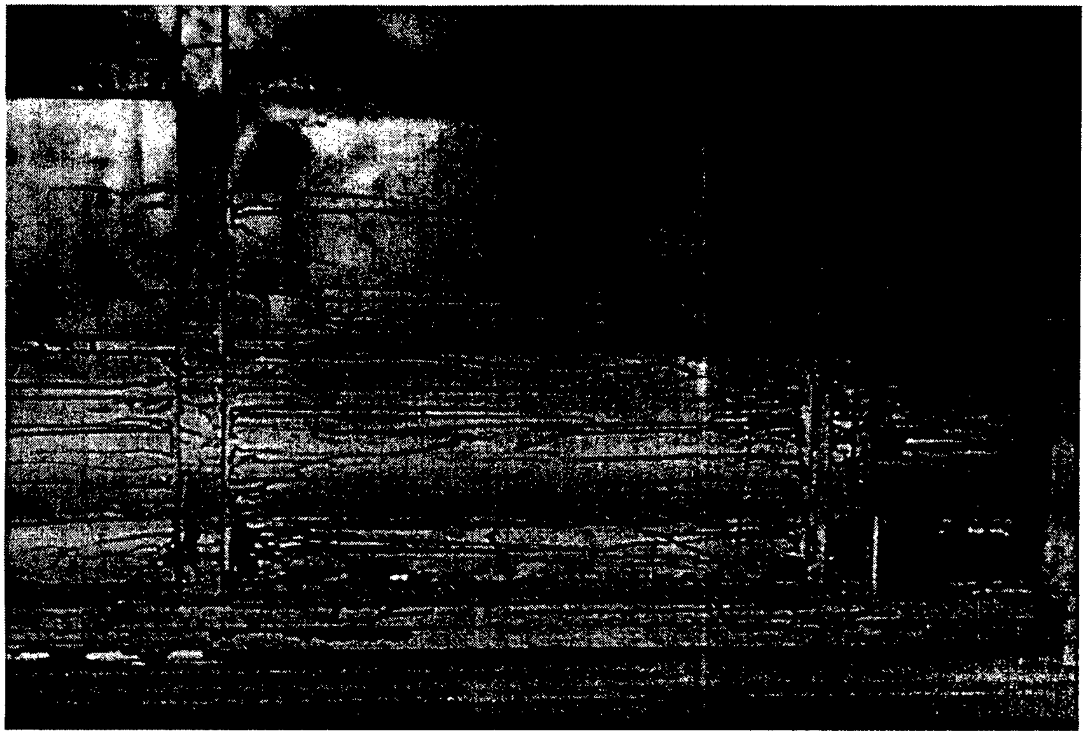

Figure B- 13. Close-up of interior of hangar door showing dents and warpage of skin plate before TSV application.

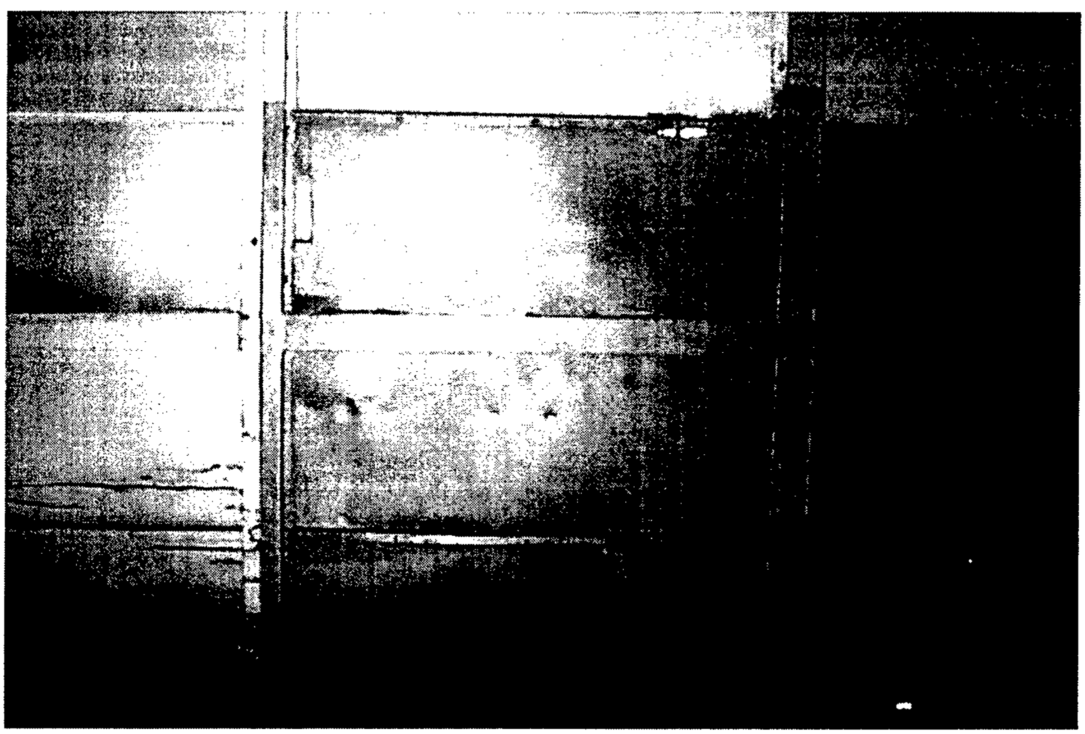

Figure B- 14. Photograph of hangar door interior after TSV and repainting showing no additional warpage.

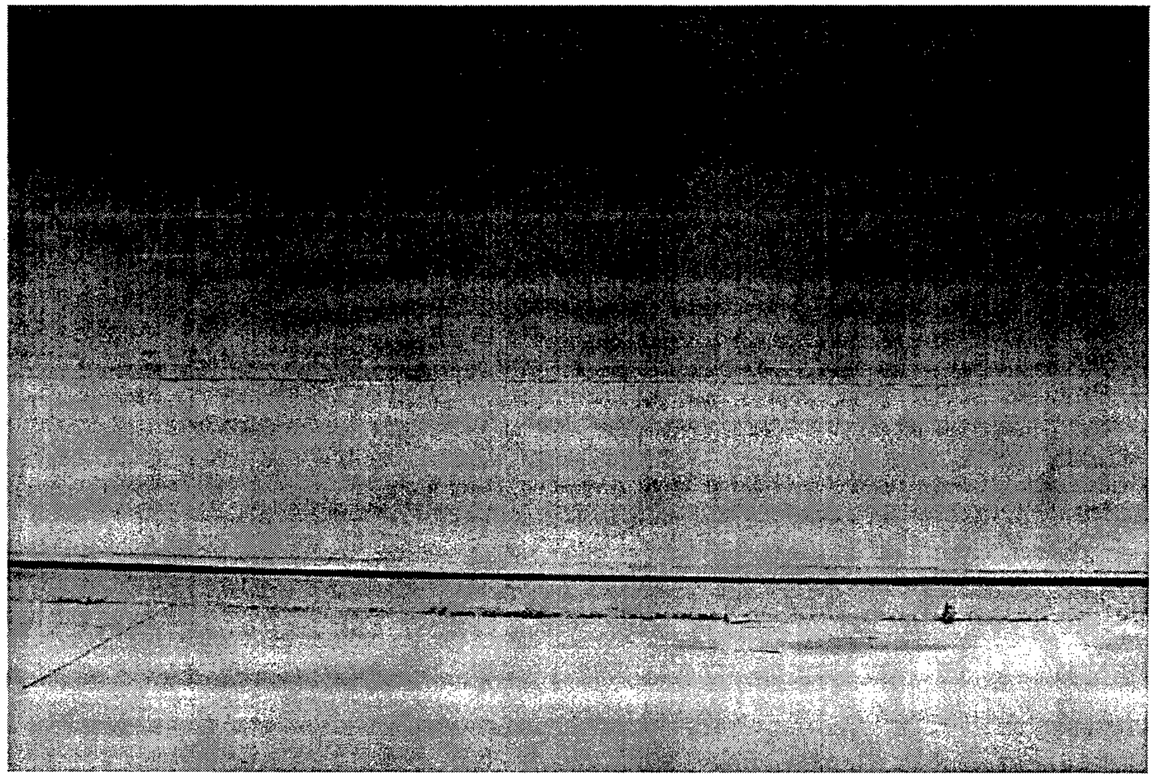

Figure B- 15. Photograph of exterior of hangar door after TSV and repainting.

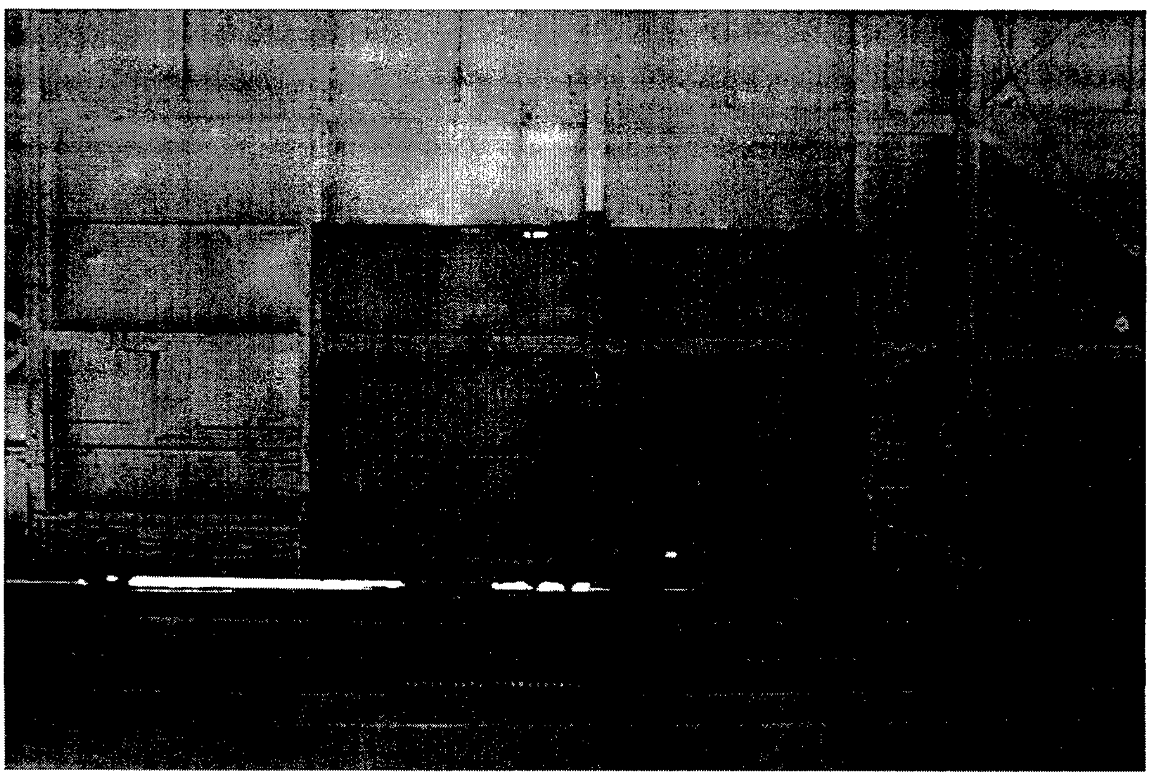

Figure B- 16. Photograph of interior hangar door after TSV and repainting.

Appendix C: Rock Island Bridge Demonstration Field Data

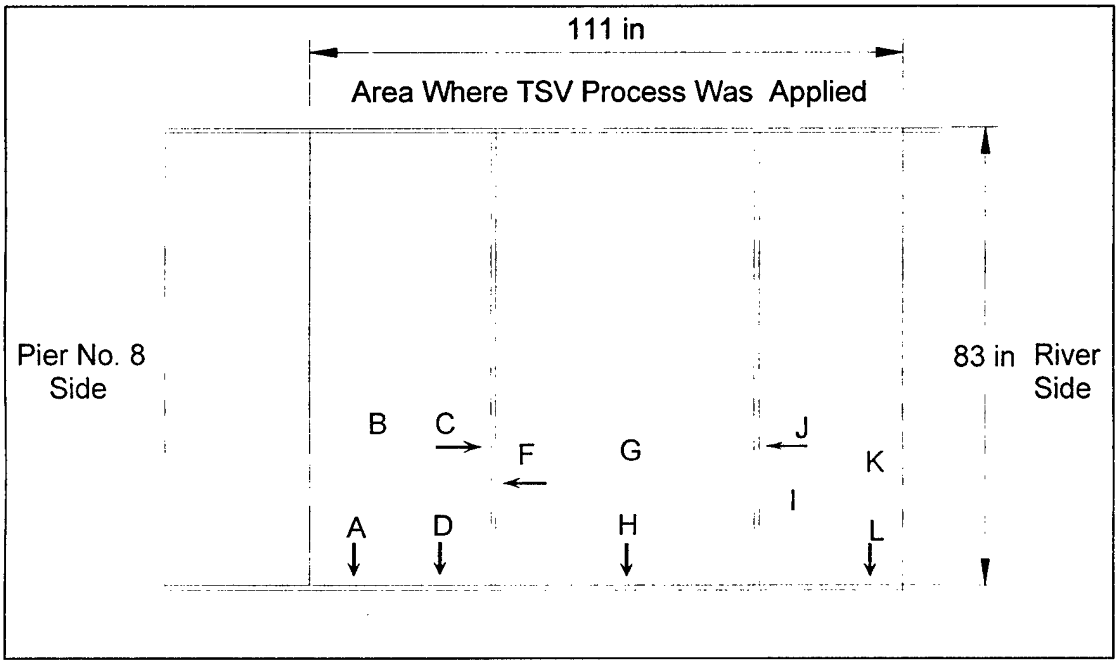

Figure C-1. Location of thickness measurements of existing paint system before application of TSV, east side.

Table C-1. Thickness of existing paint system before TSV application, east side.

Location	Measured Thickness (mils)	Measured Thickness (mils)	Measured Thickness (mils)	Average Thickness
A	11.8	10.4	9.5	10.6
B	4.7	4.3	4.4	4.5
C	6.7	7.1	7.3	7.0
D	5.0	5.5	6.3	5.6
E	3.5	3.2	3.1	3.3
F	2.3	2.2	2.6	2.4
G	5.5	6.7	5.4	5.9
H	18.1	19.6	15.7	17.8
I	7.1	6.0	6.4	6.5
j	6.3	8.3	7.6	7.4
K	9.8	9.0	7.6	8.8

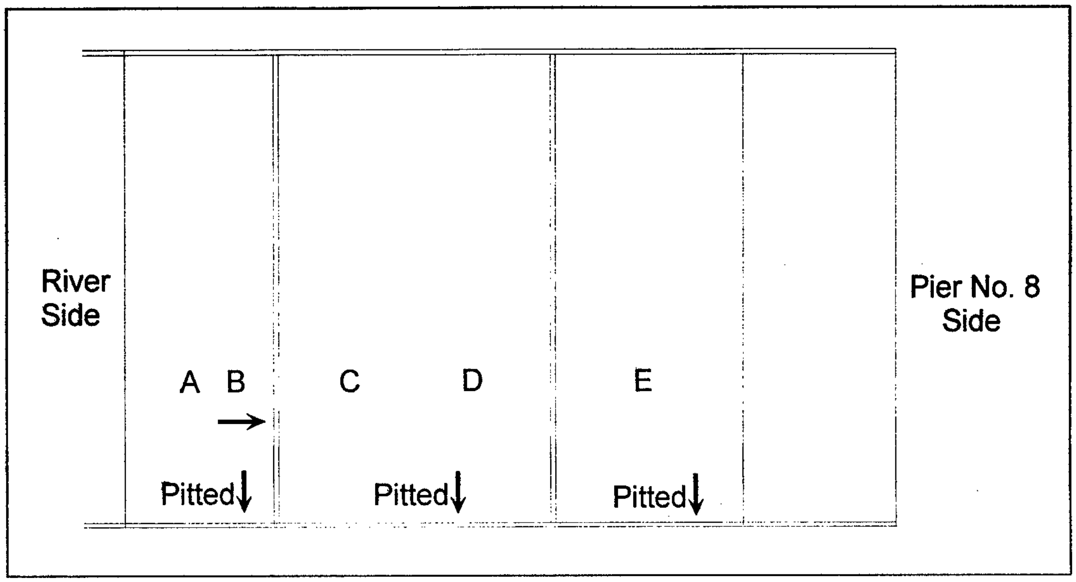

Figure C-2. Location of thickness measurements of existing paint system before application of TSV, west side.

Table C-2. Thickness of existing paint system before TSV application (west side).

Location	Measured Thickness (mils)	Measured Thickness (mils)	Measured Thickness (mils)	Average Thickness
A	3.4	3.1	3.5	3.3
B	7.2	6.4	4.6	6.1
C	4.3	4.4	4.1	4.2
D	3.5	3.1	3.2	3.3
E	3.1	3.3	3.5	3.3

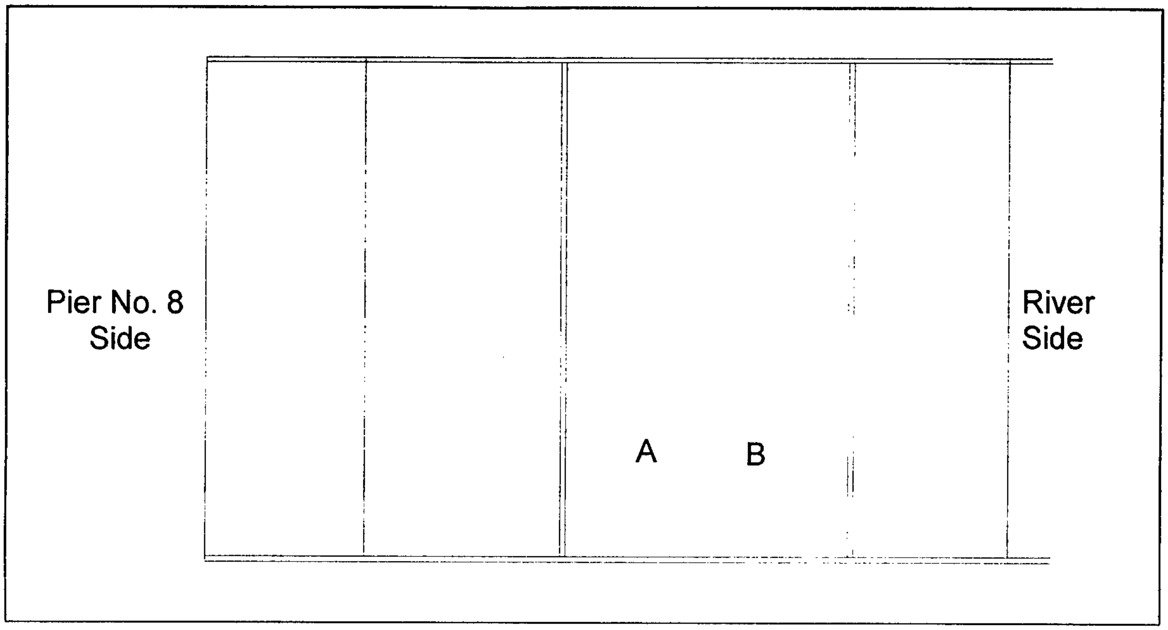

Figure C-3. Location of steel temperature measurements during TSV application.

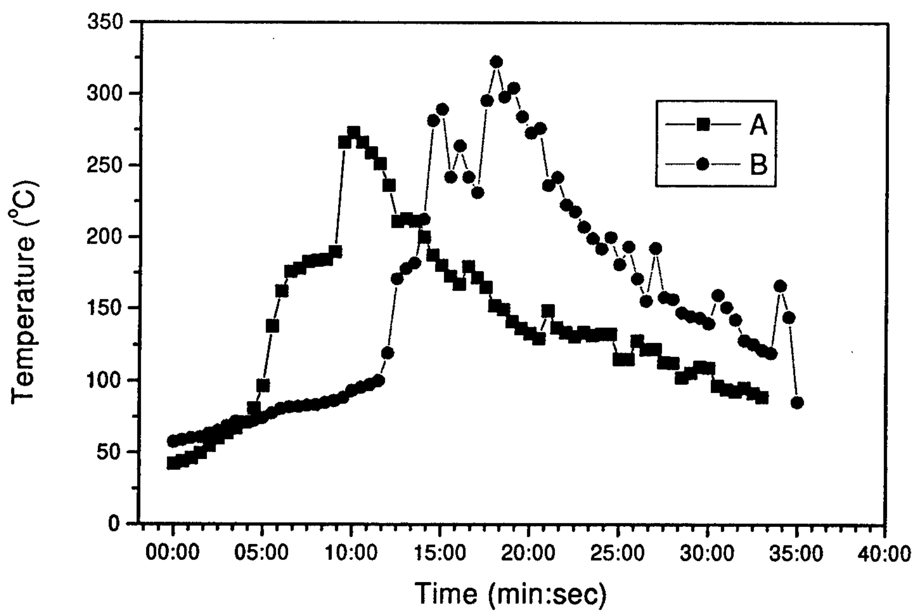

Figure C- 4. Steel temperature measurements during TSV application.

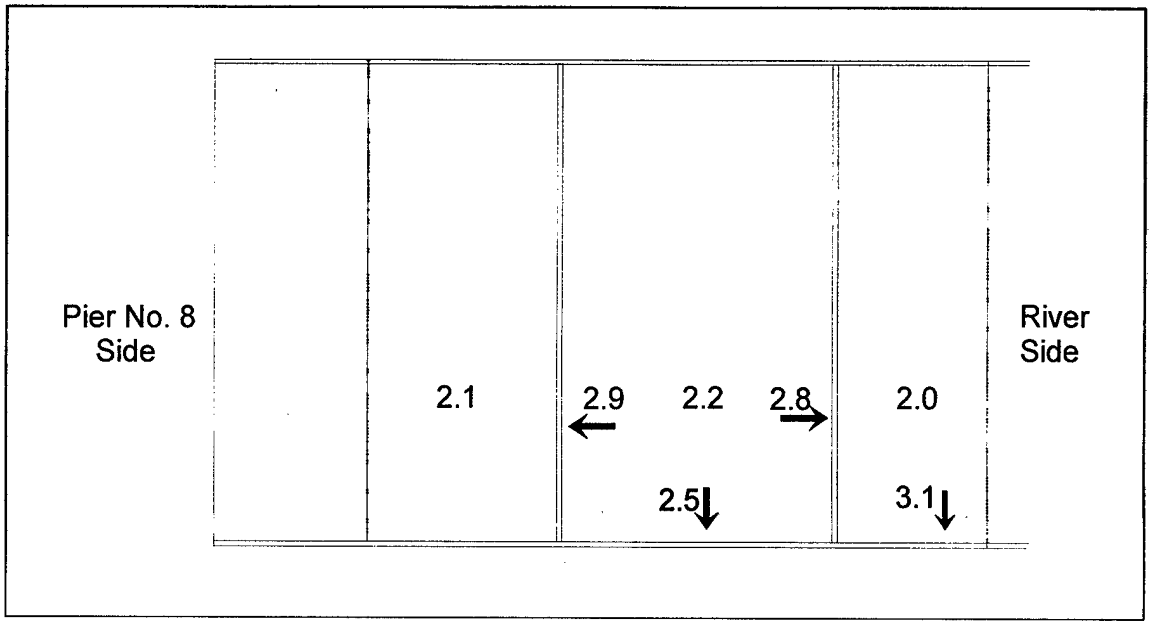

Figure C- 5. Surface profile after TSV application (mils), east side.

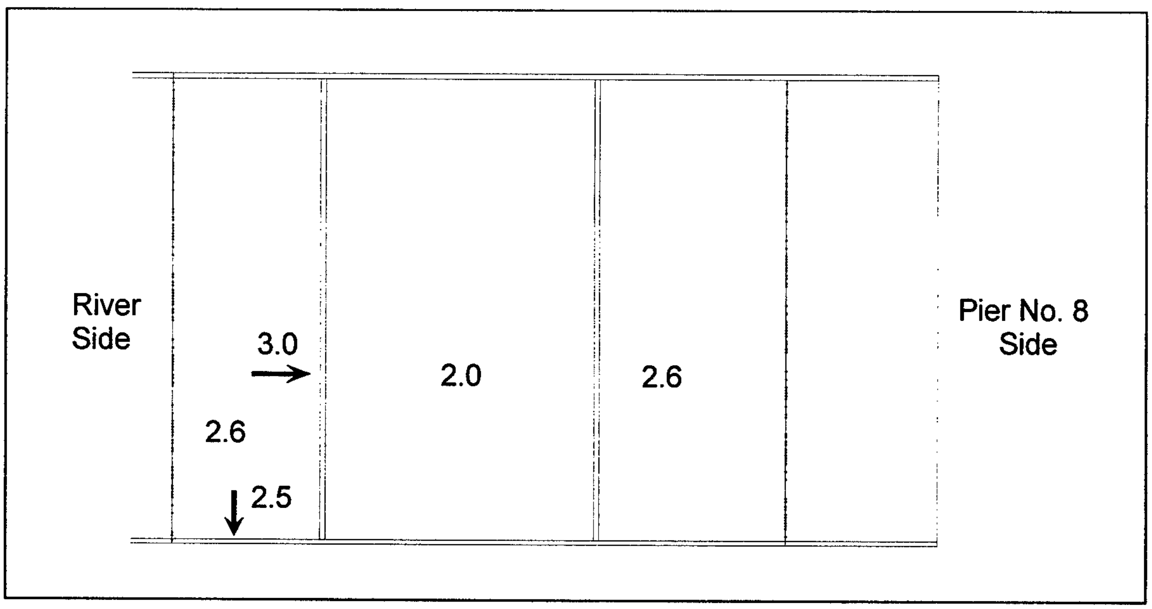

Figure C- 6. Surface profile after TSV application (mils), west side.

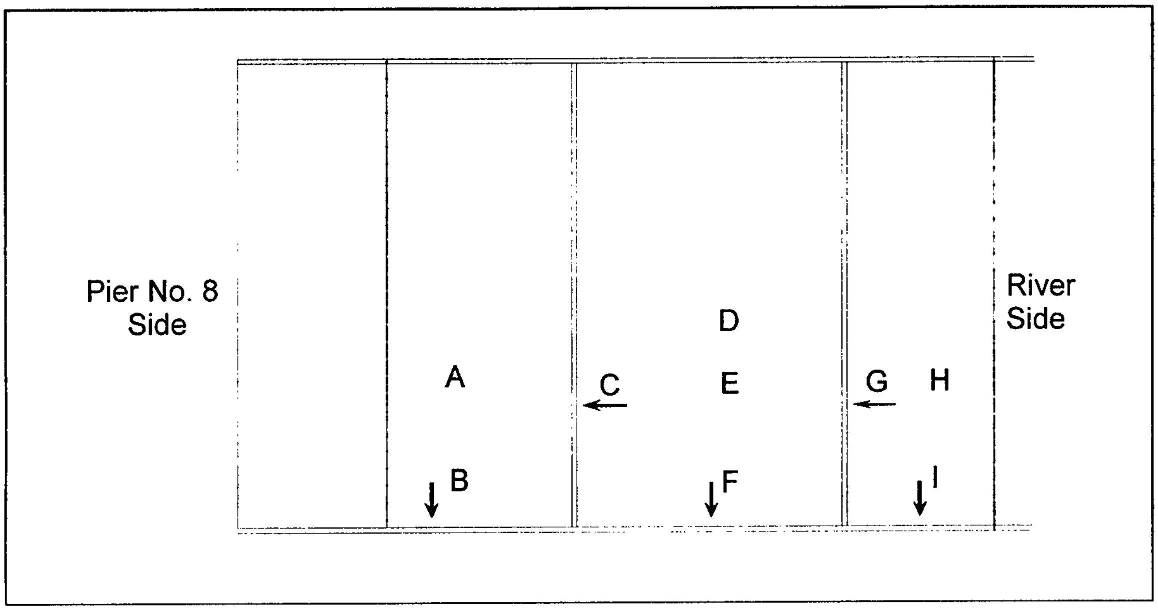

Figure C- 7. Location of primer thickness measurements after TSV application, east side.

Table C-3. Thickness of primer after application of TSV, east side.

Location	Thickness (mils)	Thickness (mil)	Thickness (mils)	Average
A	2.4	2.2	1.9	2.2
B	4.3	4.4	4.7	4.4
C	2.6	2.5	2.0	2.4
D	1.5	1.8	1.8	1.7
E	2.5	2.4	2.7	2.5
F	4.3	3.6	2.4	3.4
G	3.3	3.2	3.9	3.4
H	2.5	2.1	2.8	2.5
I	1.7	1.8	2.1	1.9

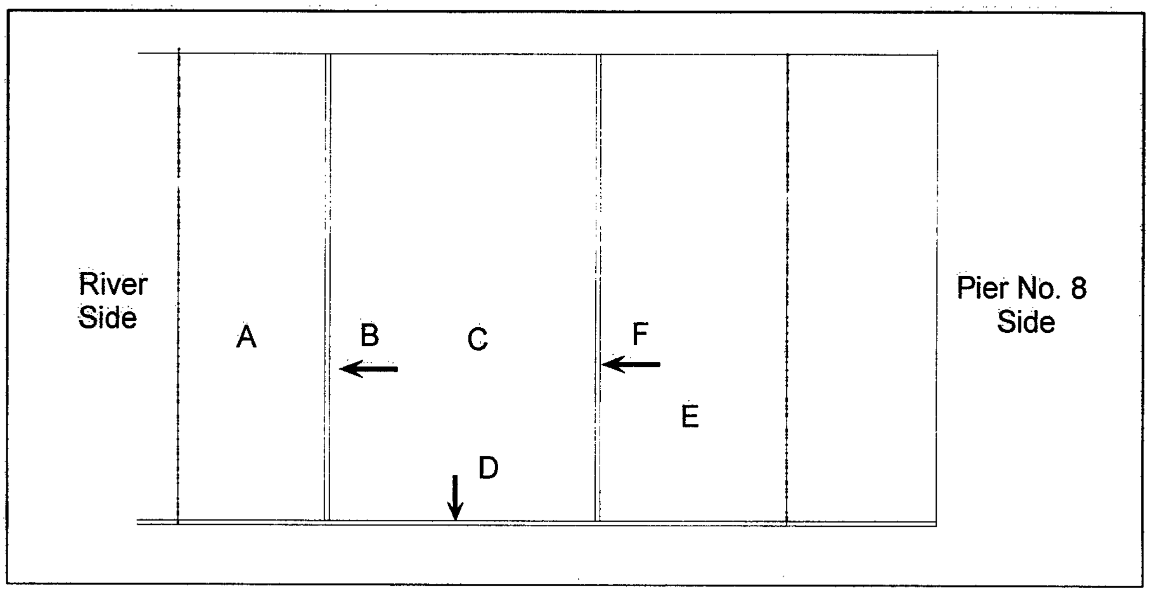

Figure C- 8. Location of primer thickness measurements after TSV, west side.

Table C-4. Thickness of the primer after TSV application, west side.

Location	Thickness (mils)	Thickness (mil)	Thickness (mils)	Average
A	2.6	2.3	2.2	2.4
B	3.0	2.7	2.2	2.6
C	2.8	2.8	3.0	2.9
D	6.0	8.8	6.6	7.1
E	1.7	2.8	2.6	2.4
F	2.3	2.5	2.0	2.3

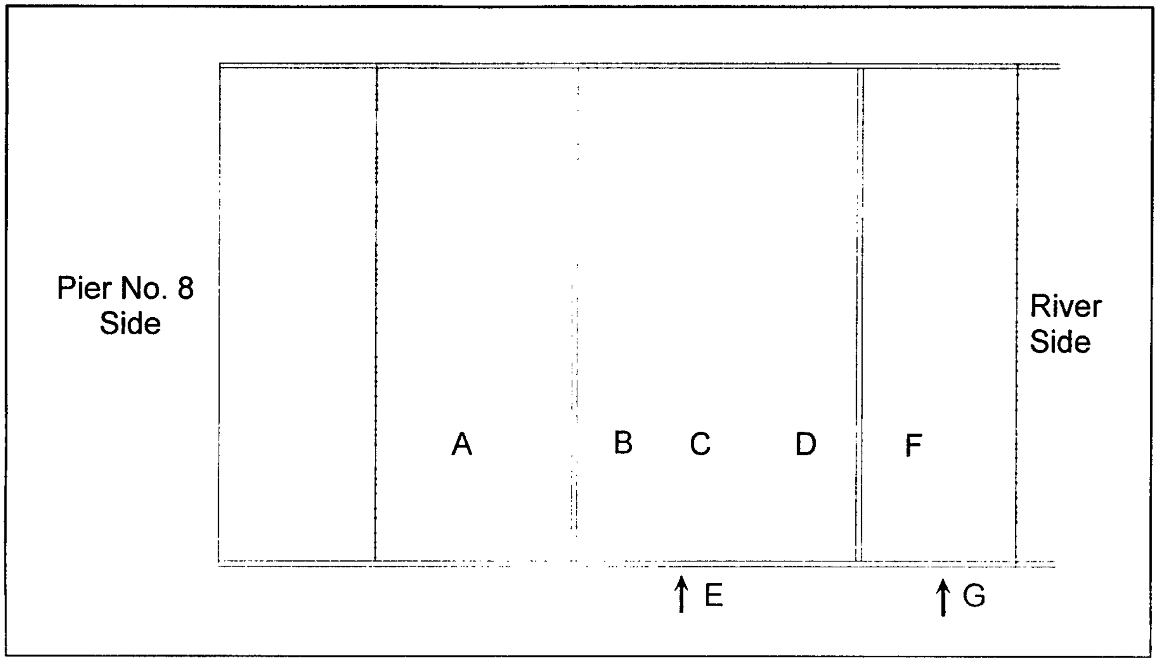

Figure C- 9. Location of thickness measurement (primer plus topcoat) after TSV application, east side.

Table C-5. Thickness of primer plus topcoats after TSV application, east side.

Location	Thickness (mils)	Thickness (mil)	Thickness (mils)	Average
A	8.2	8.4	7.4	8.0
B	6.4	6.4	6.6	6.4
C	6.6	6.4	7.7	6.9
D	7.1	8.3	7.4	7.6
E	6.6	7.6	6.2	6.8
F	6.3	6.1	6.0	6.1
G	8.3	8.4	8.5	8.4

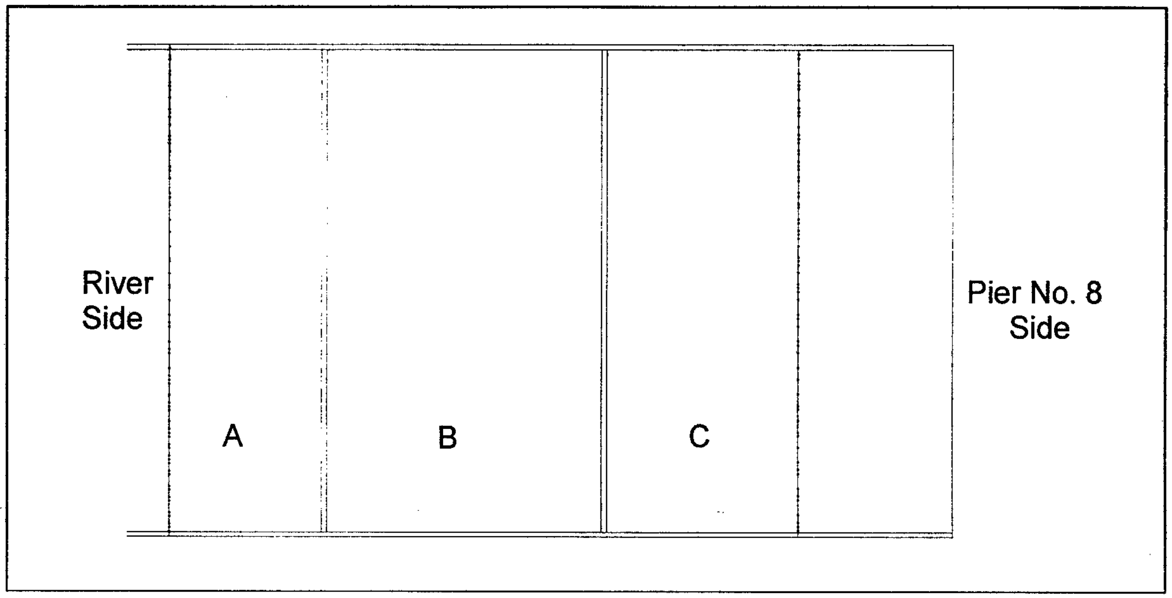

Figure C- 10. Location of thickness measurements (primer plus topcoat) after TSV application, west side.

Table C-6. Thickness of primer plus topcoats after TSV application, west side.

Location	Thickness (mils)	Thickness (mil)	Thickness (mils)	Average Thickness (mils)
A	5.0	6.0	5.3.	5.4
B	6.4	6.0	7.6	6.7
C	5.6	7.7	8.3	7.2

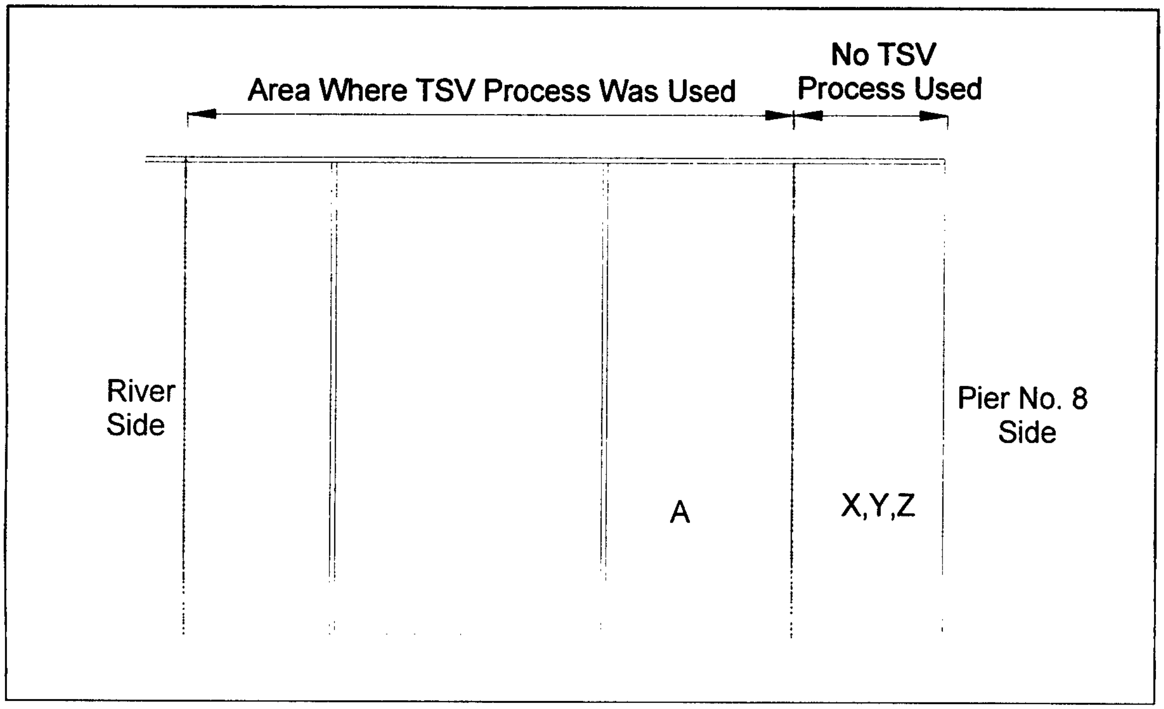

Figure C- 11. Location of lead-concentration measurements using x-ray fluorescence spectroscopy with and without TSV application, west side.

Table C-7. Lead concentration measurements using x-ray fluorescence spectroscopy after TSV application, west side.

Location	Instrument Reading No.	TSV Process Used	Lead Conc. mg/cm^2
A	107.6	Yes	2.12
X	107.7	No	4.70
Y	107.8	No	4.71
Z	107.9	No	5.84

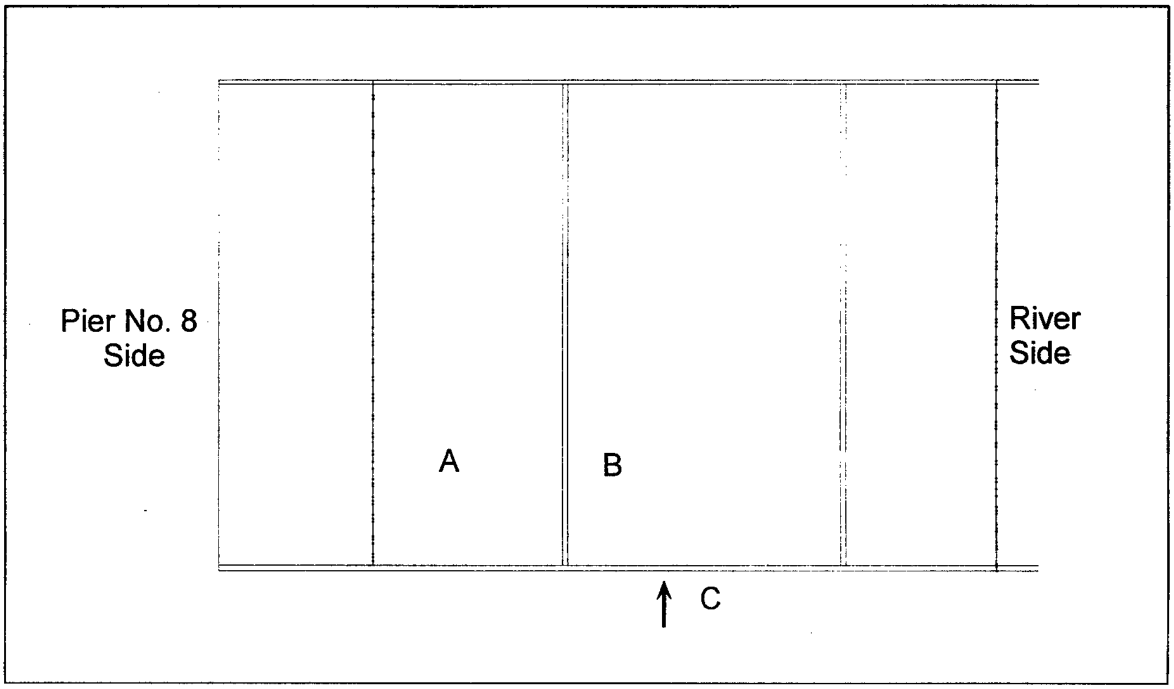

Figure C- 12. Location of lead-concentration measurements after TSV application.

Table C-8. Lead concentration using x-ray fluorescence spectroscopy after TSV application, east side.

Location	Instrument Sample No.	Lead Concentration. (mg/cm^2)
A	107.2	1.03
B	107.3	2.32
C	107.5	1.46

Appendix D: Kaneohe Bay Hangar Door Demonstration Field Data

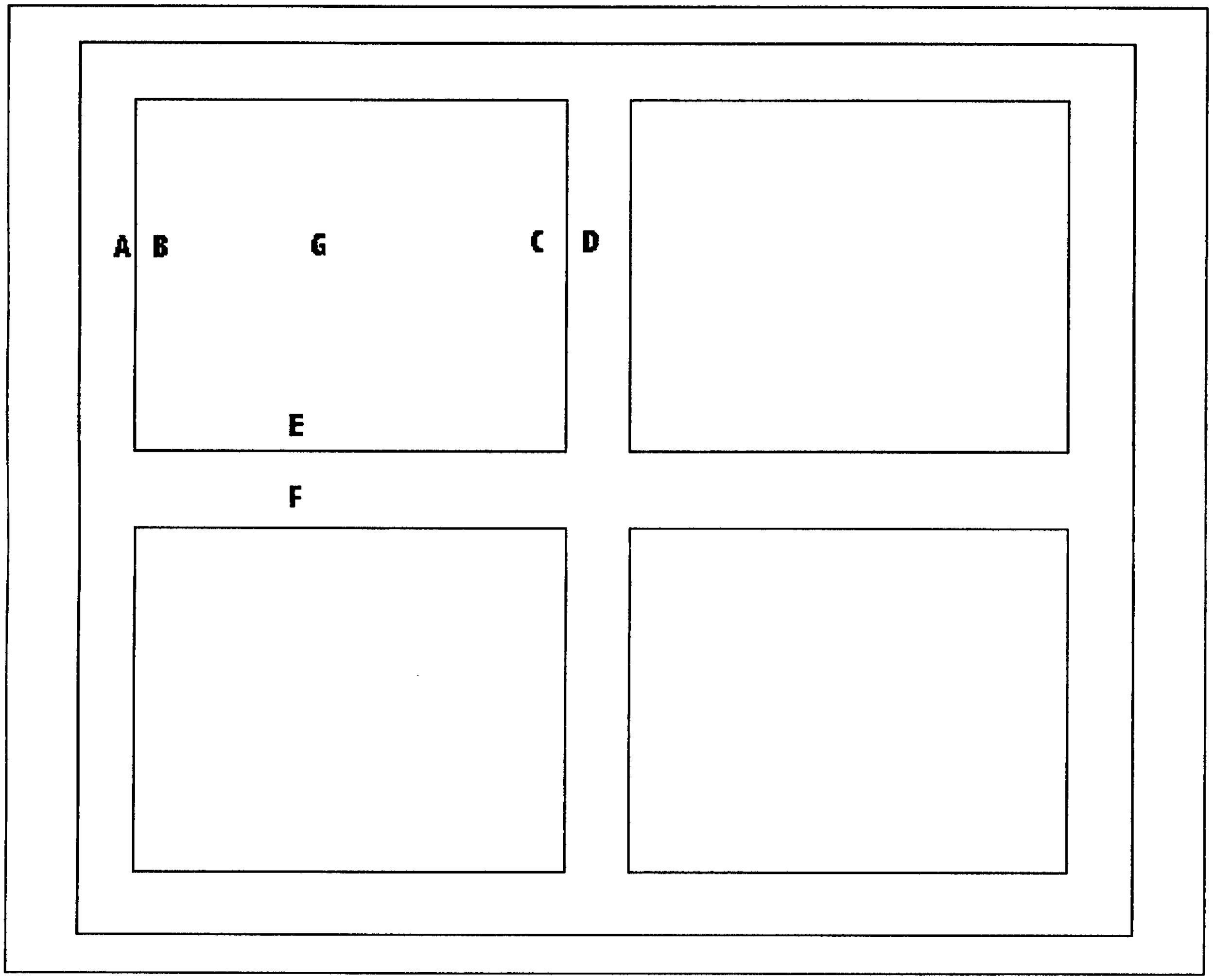

Figure D- 1. Locations of steel thickness measurements.

Table D-1. Steel thickness measurements.

Location	Component	Thickness, inches
A	Vertical Beam – Web	0.248
B	Vertical Beam – Flange	0.304
C	Vertical Beam – Web	0.274
D	Vertical Beam – Flange	0.349
E	Horizontal Beam – Web	0.202
F	Horizontal Beam – Flange	0.215
G	Skin Plate	0.139

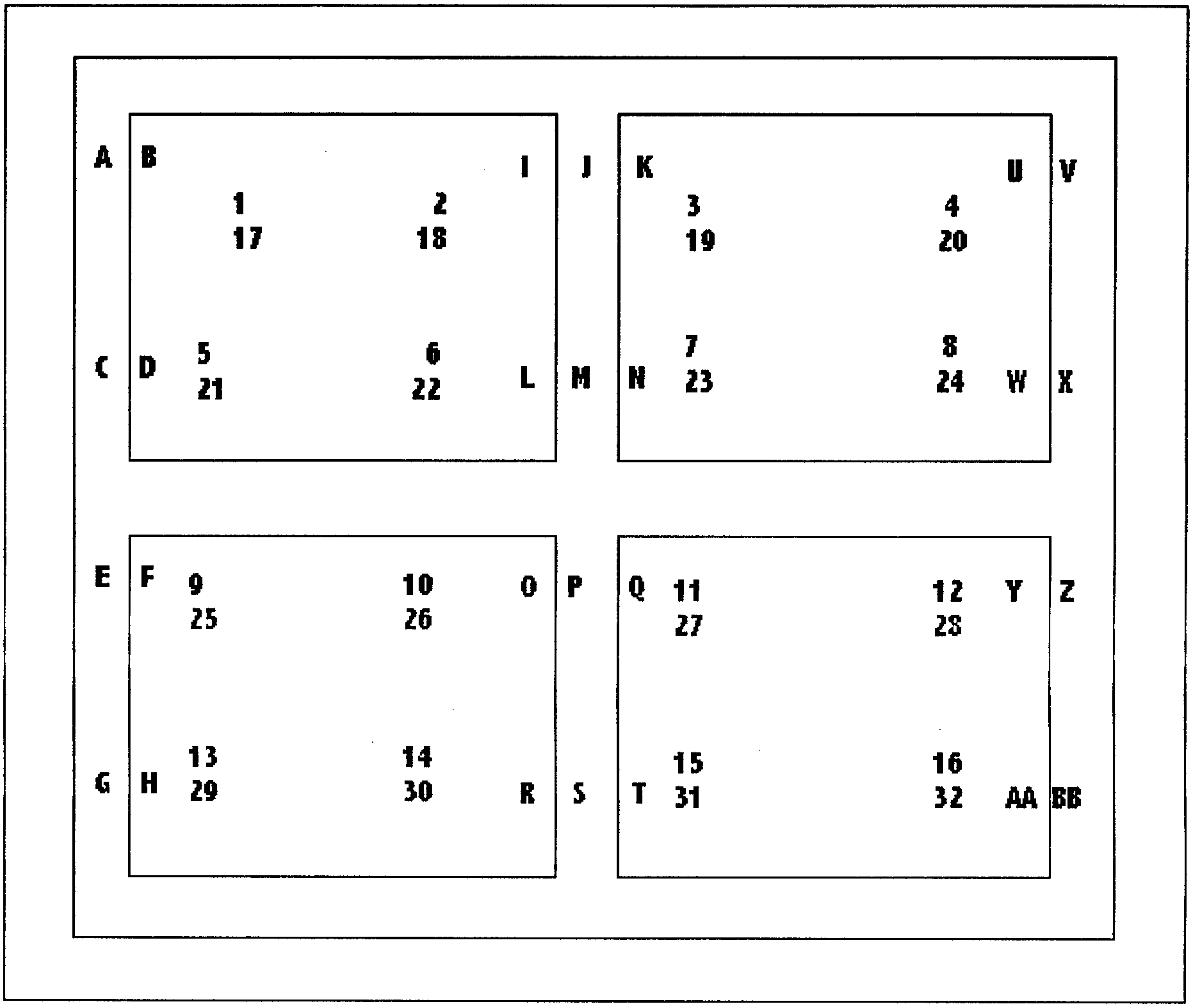

Figure D- 2. Locations of paint thickness measurements.

Table D-2. Paint thickness measurements on the skin plate.

Skin Outside	Thickness, mils	Skin Inside	Thickness, mill
1	22.7	17	7.9
2	22.2	18	7.1
3	19.1	19	5.6
4	23.2	20	5.5
5	17.8	21	7.85
6	21.1	22	8.8
7	20.3	23	7.7
8	21.7	24	6.9
9	23.9	25	5.2
10	18.9	26	4.9
11	21.5	27	7.2
12	18.5	28	7.95
13	20.6	29	8.1
14	18.8	30	7.2
15	21.4	31	7.1
16	20.5	32	8.5

Table D-3. Paint thickness measurements on the structural steel.

Left Column	Thickness, mils	Center Column	Thickness, mils	Right Column	Thickness, mils
A	10.8	I	10.7	U	11.0
B	8.8	J	10.4	V	None
C	11.0	K	9.6	W	11.4
D	9.3	L	12.9	X	9.2
E	17.3	M	11.3	Y	10.1
F	12.1	N	10.6	Z	15.3
G	14.8	O	10.8	AA	9.9
H	7.1	P	3.7	BB	5.8
		Q	10.4		
		R	9.3		
		S	3.2		
		T	10.5		

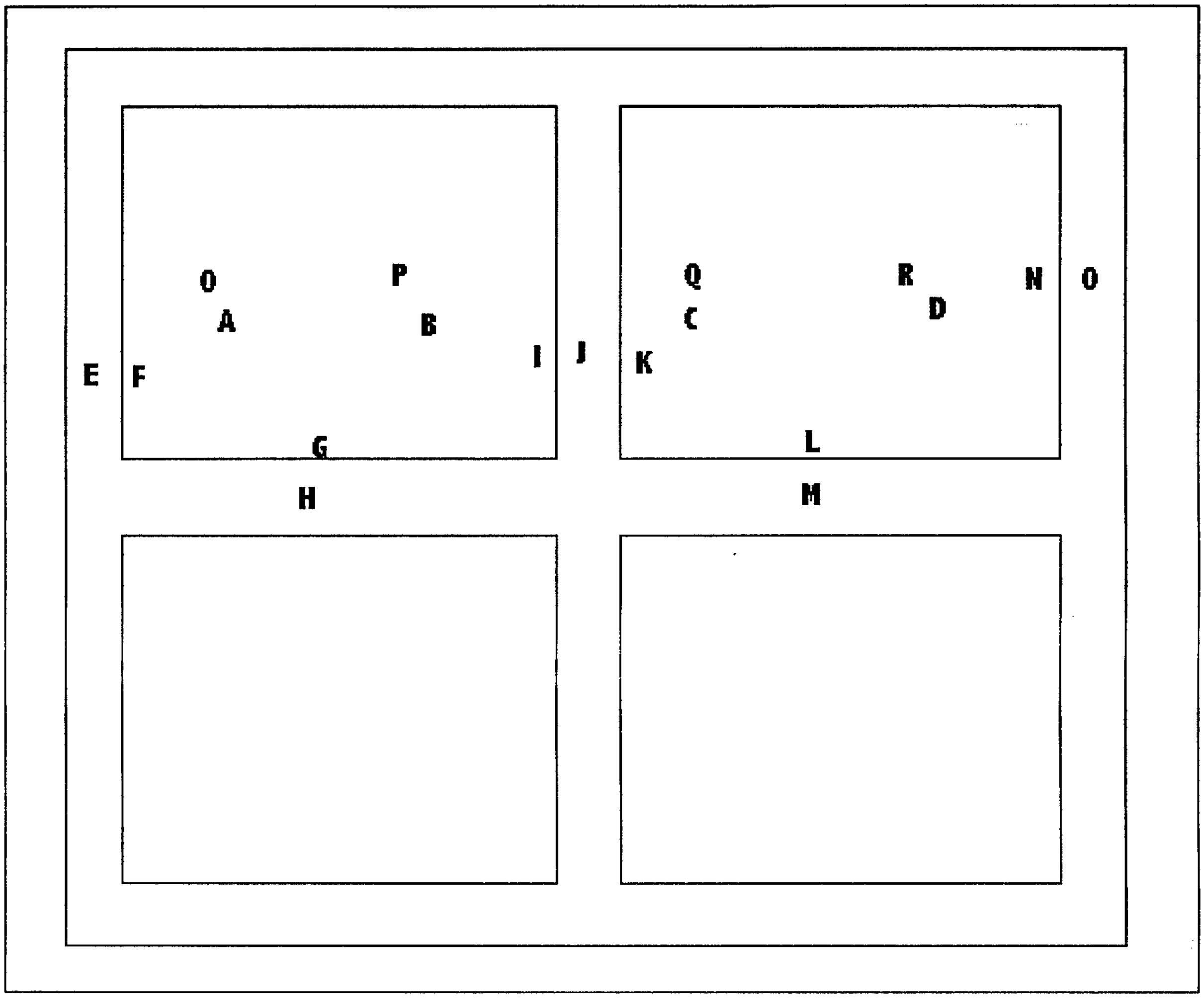

Figure D- 3. Locations of XRF measurements before TSV.

Table D-4. Lead concentration measurements before TSV.

Outside Skin	Lead, mg/cm^2	Inside Skin	Lead, mg/cm^2	Framing	Lead, mg/cm^2
A	1.72	O	4.27	E	19.95
B	2.77	P	9.07	F	12.29
C	1.43	Q	5.37	G	14.42
D	4.39	R	3.06	H	2.79
				I	16.57
				J	13.31
				K	13.76
				L	12.5
				M	9.44
				N	13.25
				O	11.5

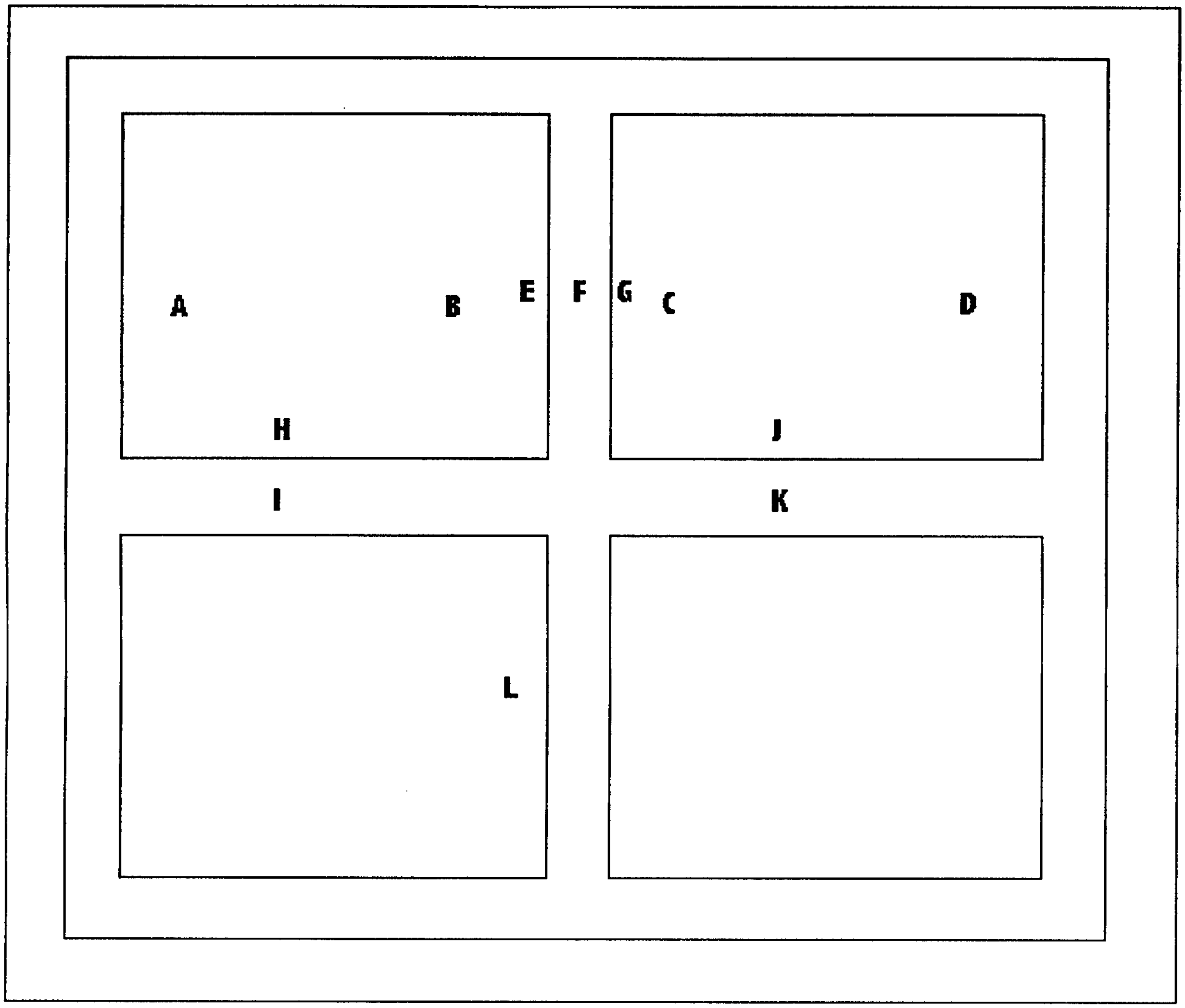

Figure D- 4. Location of XRF measurements after TSV and before needle gun cleanup.

Table D-5. Lead concentration after TSV and before needle gun cleanup.

Inside Skin	Lead, mg/cm^2	Framing	Lead, mg/cm^2
A	0.14	E	1.82
B	2.88	F	1.10
C	1.9	G	5.63
D	0.94	H	1.59
		I	2.95
		J	3.33
		K	1.29
		L	3.51

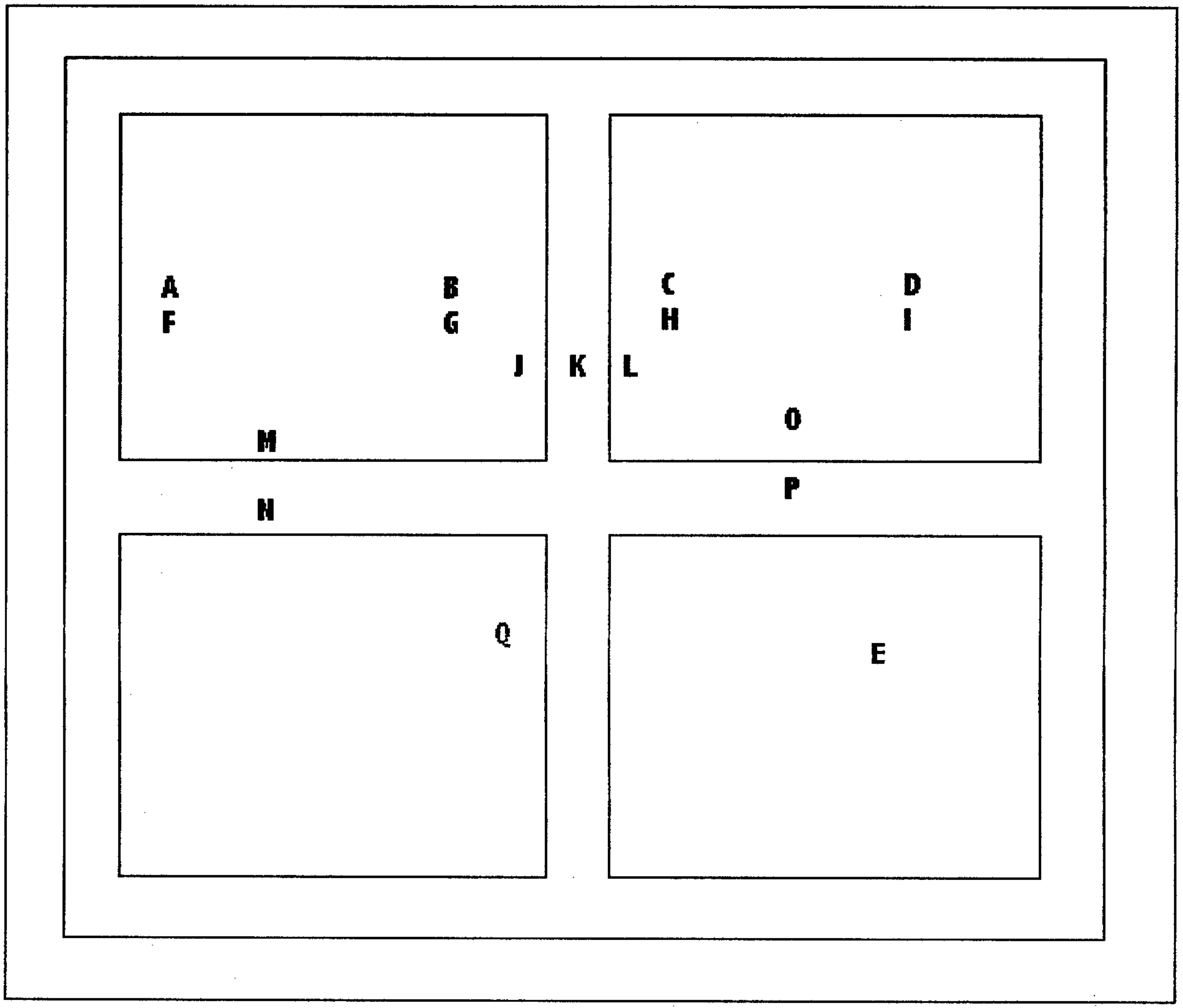

Figure D- 5. Locations of XRF readings after needle gun cleanup.

Table D-6. Measurements of lead concentration after needle gun cleanup.

Outside Skin	Lead, mg/cm^2	Inside Skin	Lead, mg/cm^2	Framing	Lead, mg/cm^2
A	1.02	F	0.27	J	1.83
B	1.22	G	1.87	K	0.07
C	0.97	H	1.85	L	4.28
D	0.67	I	0.68	M	2.71
E	1.36			N	2.03
				O	3.62
				P	1.39
				Q	3.56

Appendix E: Laboratory Testing of the Thermal Spray Vitrification of Epoxy-Polyamide Paints for Navy Ship Structures

by

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E.1 Introduction

Red lead primer has been used on many steel structures, including ships, to control corrosion. When old paint starts to peel, removal of the paint may be required before repainting. The most common method of removing paint from Navy ship structures has been the use of a dense abrasive blast media. A collateral benefit of abrasive blasting is its tendency to roughen the surface, creating an anchor profile for repainting the structure. While the method is highly effective and the procedure itself is cost-effective, abrasive blasting creates large amounts of hazardous dust and waste material. The waste stream consists of small particles of paint and abrasive blast media that is partially fragmented and a significant portion of that paint and abrasive blast media becomes airborne dust. In removal of lead-based paint (LBP) systems, the presence of lead particles in the airborne dust and waste media creates an environmental risk that must be contained. The U.S. Environmental Protection Agency (EPA) requirements mandate the use of containment structures to prevent the contamination of air, soil or water. Inside the containment structures, stringent requirements must be met to protect the workers from the high concentration of lead dust [1].

Regulations that require the monitoring of exposed workers and the release of hazardous materials have greatly increased the cost of lead-based paint removal. When EPA's Toxicity Characteristic Leaching Procedure (TCLP) reveals that concentrations of hazardous species in the leachate from lead-based paint-removal wastes exceed the regulatory limits, a licensed special waste hauler must be employed to remove the material from the site and deliver it to a licensed hazardous material disposal site [2]. Even if the waste material ultimately is found to be nonhazardous, the administrative and testing requirements add substantial costs to the overall project. Furthermore, the costs of worker health and environmental monitoring also dramatically increases the cost of LBP removal, sometimes exceeding the cost of disposal by a factor of five [3]. Innovative technologies that could effectively remove LBP from ship structures while rendering the wastes nonhazardous would be highly beneficial. One excellent candidate technology is thermal spray vitrification (TSV) [4]. This process was patented by Kumar and Patreanu and assigned to the U.S. Army [5].

The nonhazardous vitrified product may have potential use as feedstock in other glass/ceramic products. According to the recycling exemption of the Resource Conservation and Recovery Act, the vitrified product would not be classified as solid waste if it is used or reused as a ingredients in an industrial process to made a product. Recycled products currently under investigation by Seiler Pollution Control System, Inc, Dublin, OH, include abrasive grit blasting media and architectural materials [6]. The reuse of the vitrified product as feedstock for TSV is also under investigation.

Until recently, testing of lead-based paint by U.S. Army Construction Engineering Research Laboratory (CERL) has been restricted to a system of aluminum phenolic topcoat (TT-P-38E) and red lead alkyd primer (TT-P-86H). In response to U.S. Navy interest in removal of lead-based paint from ships, lead-containing epoxy-polyamide paints were tested to ensure that no significant differences in performance and safety procedures existed compared to alkyd paint systems. This included laboratory samples and a section of a painted steel structure cut from a Navy ship at the Puget Sound Naval Shipyard, Bremerton, Washington.

E.2 Experimental Procedure

E.2.1 Laboratory Samples

Sample plates (4 x 6 x 1 inch) were painted with a minimum of 12 mils of a lead-containing epoxy paint (MIL-P-24441). TSV was used to remove paint as described below. Air sampling was conducted throughout these tests. The air monitor was a Mine Health and Safety Administration (MHSA) approved Sensidyne Model 44 air sampling pump, fitted with collection cartridges supplied by Kemper Laboratory (NATLSCO). The collection cartridge was placed in the exhaust stream of the hood where work was performed. The equipment used was a Praxair (Miller)

Thermal mechanical powder feeder Model 1264, modified to accept a Sulzer Metco 6P-II-H spray gun with a P7C-K nozzle. The powder feeder contained borosilicate glass powder (Table E-1), with -230 to +100 mesh particle size (nominal 0.1 mm).

The substrate was preheated with an acetylene-rich (reducing) flame until a black coating appeared over the whole sample using the processing conditions listed in Table E-2. Using a normal flame, preheating continued, until the temperature reached approximately 200 °C at which point the actual vitrification process was begun. To do this, the powder feeder was activated and molten glass laid down. The glass was allowed to slough off and showed a tendency to do so. Glass application continued until glass adhered to the substrate. Then the sample was allowed to cool enough for glass to spall. If the spalling process left an area of glass adhered to substrate, a scraper was used to release it. The preheat/glass application was repeated a second time. The glass and paint were collected for remelt using the furnace. TCLP analysis was conducted on the remelted glass and the remaining remelted glass was properly disposed.

Table E-1. Glass composition.

Species	Wt. %
SiO_2	54.1
B_2O_3	6.8
Al_2O_3	4.1
Na_2O	10.3
Li_2O	4.7
MnO_2	2.9
NiO	0.9
CaO	1.5
MgO	0.8
Fe_2O_3	12.3
ZrO_2	1.2

Table E-2. Gas pressures and flow rates to the spray gun.

	Normal Flame		Reducing Preheat Flame	
Material	Pressure (psi)	Flow Rate (%)	Pressure (psi)	Flow Rate (%)
Oxygen	45	42	45	10
Acetylene	14	50	14	50
Compressed Air	5	N/A	5	N/A
Glass powder	N/A	89 g/min	N/A	N/A

E.2.2 Ship Structure Plates

The Puget Sound Naval Shipyard, Bremerton, WA, cut painted steel plates from a Navy ship. The procedure described above for TSV was used to remove the paint from the a ship structure plate. The steel plate from the Navy ship structure was 5/8 inches thick and was approximately 15 x 18 inches. The thickness of the paint ranged from 10 to 40 mils.

The suitability of steel to be abrasively blasted after application of TSV was investigated in the laboratory. Lead-based-paint was removed using TSV from a steel specimen from a highway bridge coated with a red lead primer and alkyd topcoat. Although the surface was suitable for repainting with a surface tolerant system, there is the possibility that some residual lead may remain on the surface. Subsequent abrasive blasting may contaminate the blast media creating a waste that would be classified as hazardous. In the laboratory test, new abrasive blast media was used to clean the specimen after application of TSV. The mineral abrasive, Black Beauty (Reed Mineral Corp.), is used by the Navy for abrasive blasting of ships and was used in this test. TCLP analysis was then conducted on the blast media.

E.3 Results and Discussion

TSV was successful in removing the Navy paint system, Mil P 24441 epoxy polyamide paint containing lead pigments, from laboratory samples. The surface quality was suitable for repainting with a surface-tolerant system after cleaning described in Steel Structures Painting Council (SSPC) SP-3 [7]. It is noteworthy that much relatively loose debris remained on the plate after the glass spalled. The amount of glass used in TSV for the removal of epoxy-polyamide paint was similar to that previously found to be necessary for the removal of phenolic and alkyd paints, which is about 1/2 lb. of glass per sq ft. Results of the air monitoring showed that the TSV process did not exceed the regulatory standards for airborne lead. Airborne lead concentrations were less than 10 $\mu g/m^3$ (Table E-3). TCLP analysis showed that the concentration of lead in the leachate was less than 1.5 mg/L for the remelted glass, below the EPA regulatory standard of 5 mg/L. This is consistent with previous results of TCLP analysis of remelted glass obtained by TSV for removal of phenolic and alkyd paint systems.

Table E-3. Results of environment monitoring.

Test	Results	Regulatory Standard
TCLP analysis of remelted glass	1.5 mg/L	5.0 mg/L
Airborne lead concentration	Less than 10 $\mu g/m^3$	50 $\mu g/m^3$

TSV was also successful in removing the Navy paint system, Mil P 24441 epoxy-polyamide paint, from the ship structure plates. The resulting surface was suitable for repainting using a surface tolerant coating system which would be suitable for non-immersion applications.

For immersion applications, more durable paint systems that are not surface tolerant must be used. These paint systems require the steel surface be abrasively blasted after application of TSV. The possible presence of residual lead on the surface may contaminate the abrasive blast media used to prepare the surface. The initial concentration of lead on the painted steel measured using a X-ray fluorescence analyzer was 12.54 mg/cm^2. Following the application of TSV, the concentration of lead on the steel was less than 1.0 mg/cm^2. Three passes of TSV process was used to remove the lead-based paint such that there was no visual evidence of paint remaining on substrate. Laboratory testing found that 5 lbs of Black Beauty mineral abrasive were required per sq ft of the surface that was abrasively blasted. After abrasive blasting of the steel specimen, TCLP analysis of the media found it to leach less than the regulatory limit of 5 mg/L Pb, Table E-4. Therefore, the TSV process followed by abrasive blasting can be used to prepare surfaces for the painting with a full range of paint systems. As previously indicated, TSV can be used to remove lead-based paint from ship structures which are repainted with a surface tolerant coating system. TSV is also suitable for ship structures that are going to be demolished without further repainting.

Table E-4. TCLP Of abrasive blast media used on TSV-cleaned steel specimens.

	TCLP Analysis for Pb	**Regulatory Limit**
Sample A	0.20 mg/L	5.0 mg/L

E.4 Comparison to Hydroblasting

A demonstration of TSV was provided on 23 September 1977 by CERL for Mr. Stephen Hobaica of the Naval Surface Warfare Center and Mr. Ray Travis, Mr. Richard Olsen and Mr. Mel Herbstritt of the Puget Sound Navy Shipyard. The advantages and disadvantages of TSV were discussed in comparison with the hydroblasting process. Applications where TSV would address Navy needs were determined. The hydroblasting process uses high pressure water to remove lead-based paint and has been tested at the Puget Sound Naval Shipyard and is shown in Figure E-1. The hyrdroblasting process can be used only on the outside of the ship on the hulls, while TSV can be used both inside and outside of the ship hulls. Vitrification stabilizes the lead and other hazardous metals so that they can be disposed as nonhazardous waste. This is in contrast to the hydroblasting process which does not stabilize the hazardous metals and results in the entire

volume of water used in the process being contaminated and classified as hazardous waste. The production rate for vitrification is much slower (30 sq ft per hour) than for the hydroblasting process (200 sq ft per hour). Overall the two technologies are complimentary because the vitrification process can be used inside the ship and in tight spaces and the hydroblasting process can be used on large flat areas of the ship hull.

E.5 Conclusions

TSV was successful in removing lead-containing epoxy-polyamide paint from laboratory samples. TSV was also successful in removing epoxy-polyamide paint from Navy ship structure plates. The results of air monitoring during lead paint removal using TSV was 10 $\mu g/m^3$, below the regulatory standard of 50 $\mu g/m^3$. The result of TCLP analysis of the remelted glass was 1.5 mg/L, below the regulatory standard of 5.0 mg/L. The environmental advantages of TSV are similar for epoxy, phenolic, and alkyd paint systems. TCLP analysis of abrasive media used to clean the steel surface after TSV leached less than the regulatory limit of 5 mg/L Pb. The advantages of TSV compared to the hydroblasting process are that TSV can be used inside the ship and the resulting TSV waste is nonhazardous.

E.6 Recommendations

1. For immersion application on Navy ships, TSV can be used to removed lead-based paint followed by subsequent abrasive blasting to prepare the surface for painting.

2. For air exposure applications on Navy ships, TSV can be used to remove lead-based and followed by painting with a surface tolerant coating system.

3. For ship structures that are to be demolished and not repainted, TSV can be used to remove lead-based paint.

4. A full demonstration and validation of TSV for Navy ship structures should be conducted at the Puget Sound Naval Shipyard as scheduled in FY99.

E.7 References

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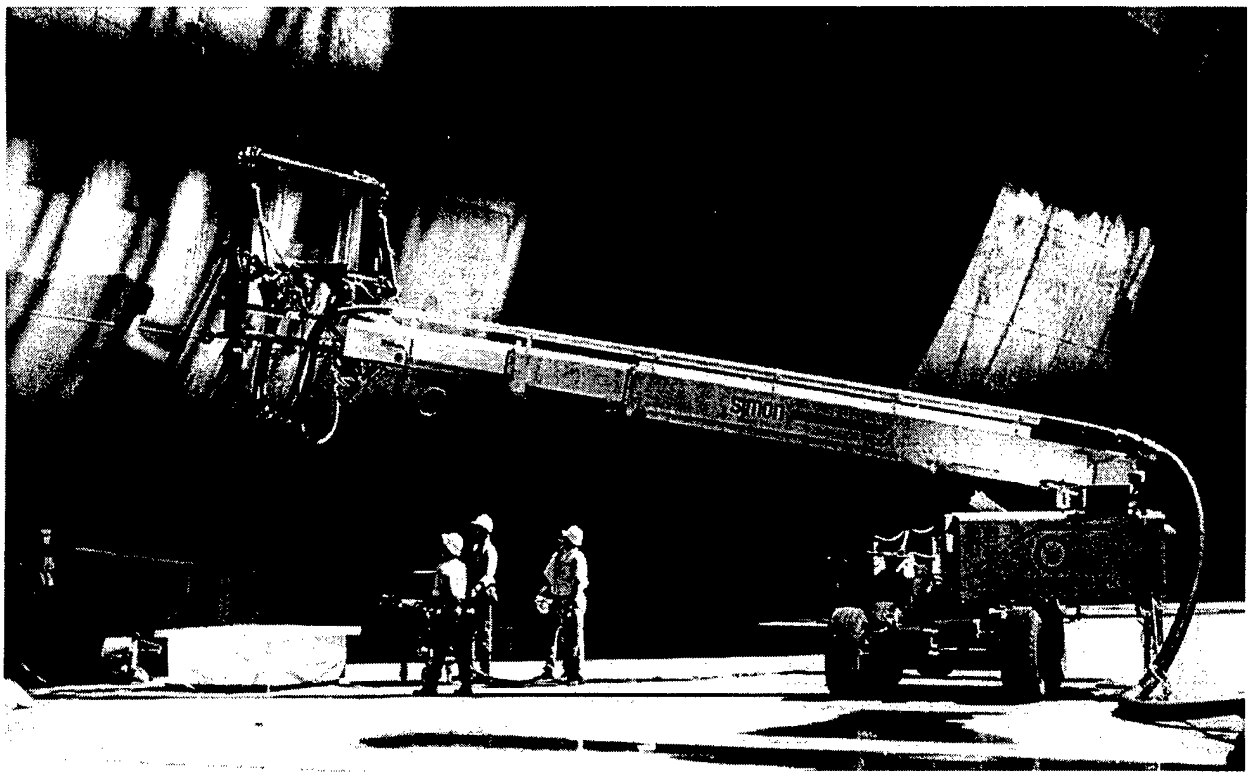

Figure E- 1. Hydroblasting of a ship hull.

Appendix F: Demonstration of Thermal Spray Vitrification to Remove Lead-Containing Paint on Fire Hydrants at Tyndall AFB, FL

F.1 Introduction

The thermal spray vitrification (TSV) process for removal of lead-based paint was developed at CERL for use on steel structures. It uses standard flame spray equipment to spray melted glass particles onto the painted surface. Figure F-1 is a schematic of the equipment used in the process. The glass splat cools on the steel and removes a layer of lead oxide. Differential cooling of the glass and steel cause the glass to fall off the steel. The pieces of glass are collected and remelted in a furnace. Figure F-2 shows the remelting furnace. The remelting process causes the lead oxide to migrate into the crystal structure of the glass. Once incorporated in the silicon tetrahedral of the glass the chemical bonds retain the lead and it will not leach out. This insures that the glass waste is nonhazardous.

F.2 Problem

Tyndall AFB and all military installations have fire hydrants that are painted. Figure F-3 shows a typical fire hydrant at Tyndall AFB. Most have lead-based paint on them. Removal of the lead-based paint can be a costly process by conventional methods. This would require either a complete enclosure around each individual hydrant that is large enough to do the abrasive blasting or removal of each hydrant to a special area with a containment structure for abrasive blasting. Abrasive blasting leaves a residue of sand and paint chips, approximately 8 - 10 pounds per sq ft of surface, that is considered a hazardous waste. The disposal of this residue requires special handling. If the hydrant is removed for sand blasting, the section of water pipe that protrudes through the ground still has to be dealt with.

F.3 Approach

The approach for this demonstration is to remove the lead-based paint in-situ with TSV. A sheet metal tray was fabricated in two sections with a hole in the middle for the water pipe to pass through. The tray was three feet square and had a two inch high lip around the perimeter. The hydrant will be heated from the ground up and the paint removed in sections starting from the ground to the valve stem. After all the lead-based paint is removed then the hydrant will be wire brushed to remove the remaining glass. The glass will be collected into a stainless steel pot and stored until remelting. Remelting will be done on all glass from the vitrification process and the remelted glass will be tested by the TCLP test for leach able lead. The hydrant will be tested for seal integrity and repainted with lead free paint. The paint recommended for painting on the vitrified surface is a surface tolerant coating.

F.4 Results and Discussion

The first fire hydrant was near Building 6029 on Tyndall AFB. The hydrant was two feet tall and was connected to a water pipe that stood two feet out of the ground. The wall thicknesses at various spots was measured with an ultrasonic thickness gauge. The pipe wall thickness is 0.310 inches, the barrel of the hydrant is 0.638 inches, and the hydrant cap is 0.518 inches. The area around the hydrant was cleared of tall weeds and the collection pan was placed around the base of the pipe (Figure F-4). The equipment was assembled and the heating begun. The setup time was approximately 45 minutes starting from scratch (Figure F-5). The vitrification of the hydrant took approximately 95 minutes (Figure F-6). The hydrant was cleaned with a wire brush, which required another 30 minutes (Figure F-7). Final cleanup of the area took another 20 minutes. The second hydrant was near building 6027 and also stood four feet tall (Figure F-8). Setup time took less than thirty minutes and the vitrification took 90 minutes. Cleanup with a wire brush required 20 minutes. Final cleanup of the area took another 20 minutes.

The collected glass was all put in the remelt furnace and the burner started (Figure F-9). The glass was melted after 2 2 hours of heating. The glass was allowed to heat for a total of 4 2 hours before being poured into the stainless steel container filled with water. Less than 10 pounds of glass powder was used for the complete demonstration.

Testing of the hydrants after cooling by opening the valve and filling the body with water under pressure showed that the seals and gaskets on the first hydrant were adversely affected by the heat of vitrification. Repair of the hydrant will require about $60 worth of gaskets and seals and about 2 man-hours of labor. The second hydrant was tested and no damage to the gaskets or seals was found. An analysis of the procedures used on each hydrant showed that the first hydrant was overheated because of improper gas pressure for the glass feed system. As a result, heating was not uniform throughout the hydrant. The feed gas pressure was properly set for the second hydrant from the beginning.

The remelted glass was tested for leach able lead using the TCLP method. The results of the method was 0.07 mg/l of lead, which falls well below the limit of 5.0 mg/l of lead. The remelted glass then is considered a nonhazardous waste material and can be disposed of accordingly.

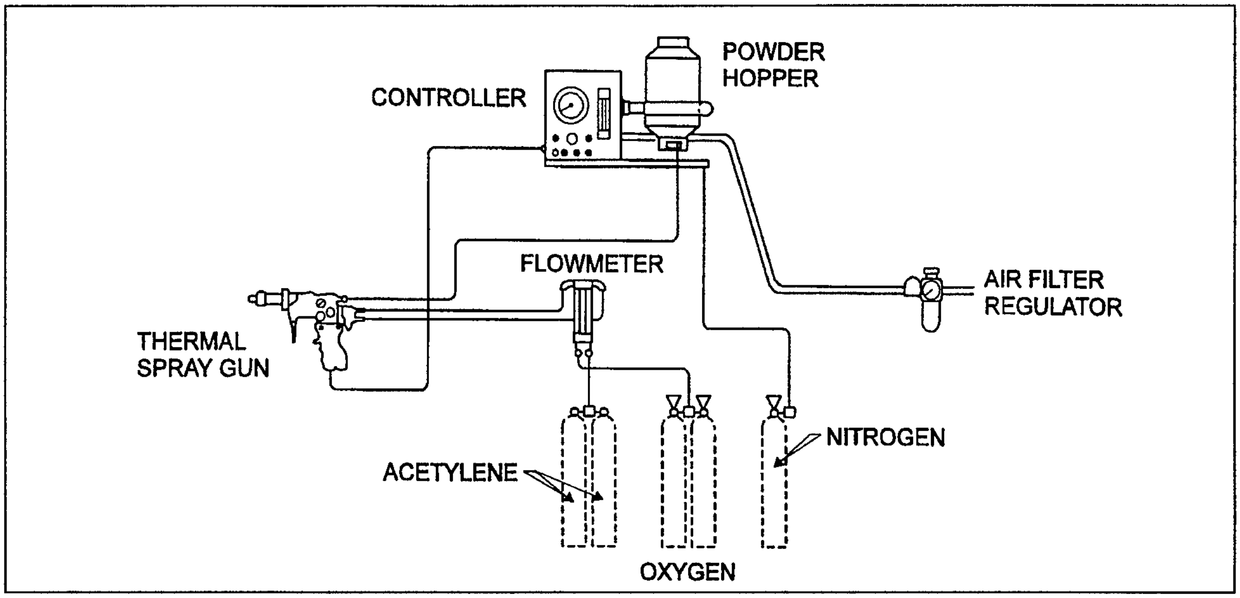

Figure F- 1. Schematic diagram of TSV system equipment.

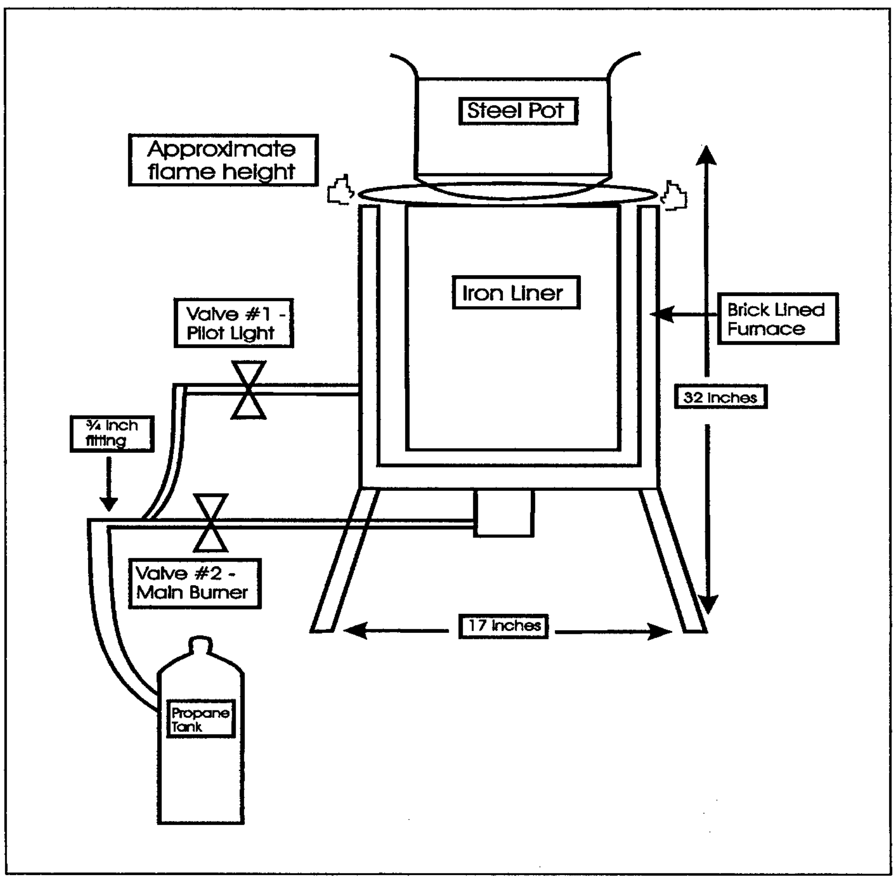

Figure F- 2. Schematic of glass remelt furnace.

Figure F- 3. Typical fire hydrant at Tyndall AFB, FL.

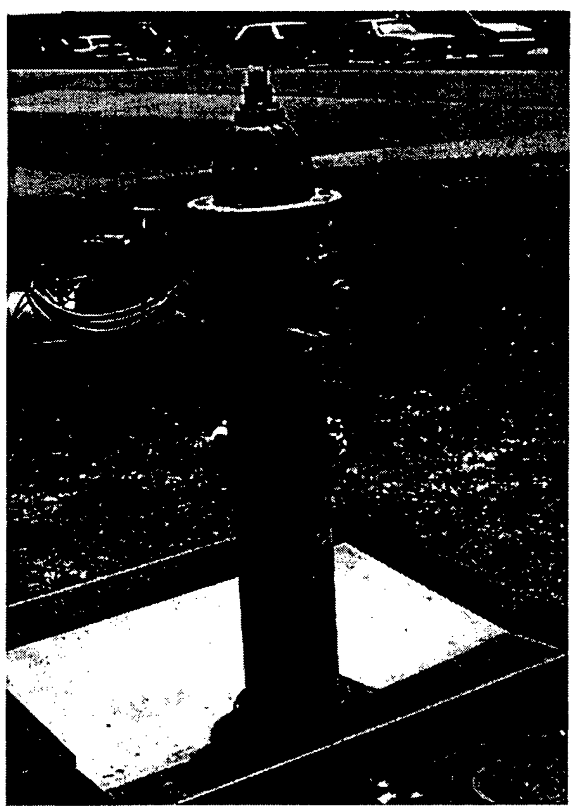

Figure F- 4. Fire hydrant near Building 6029 with collection pan.

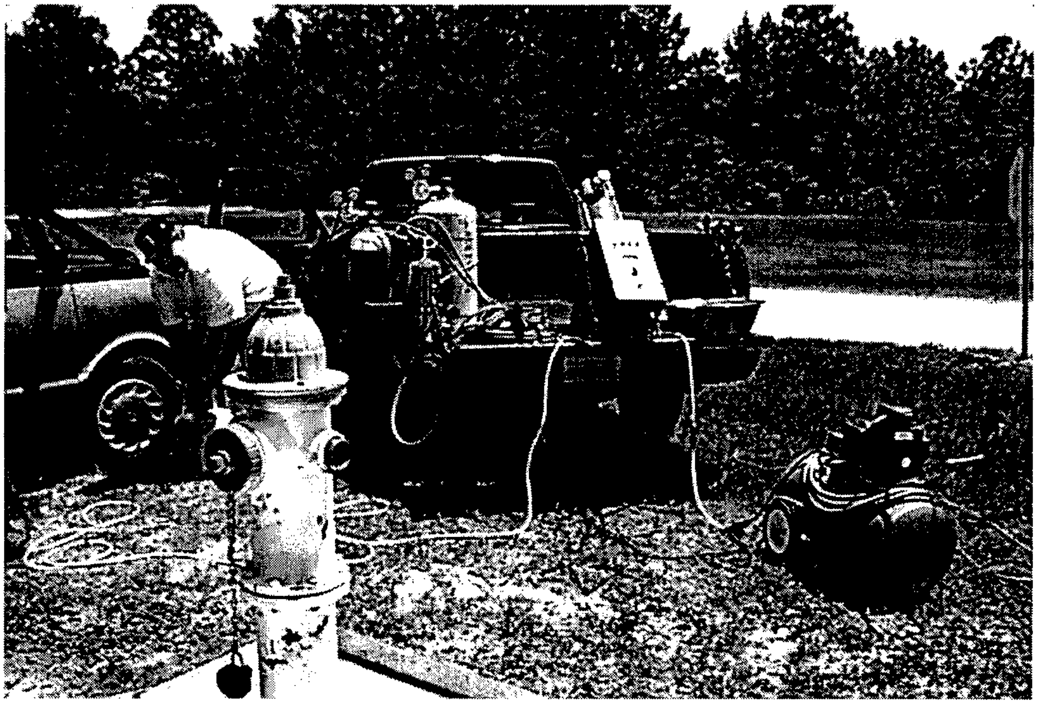

Figure F- 5. Preparations for TSV application on hydrant near Building 6029.

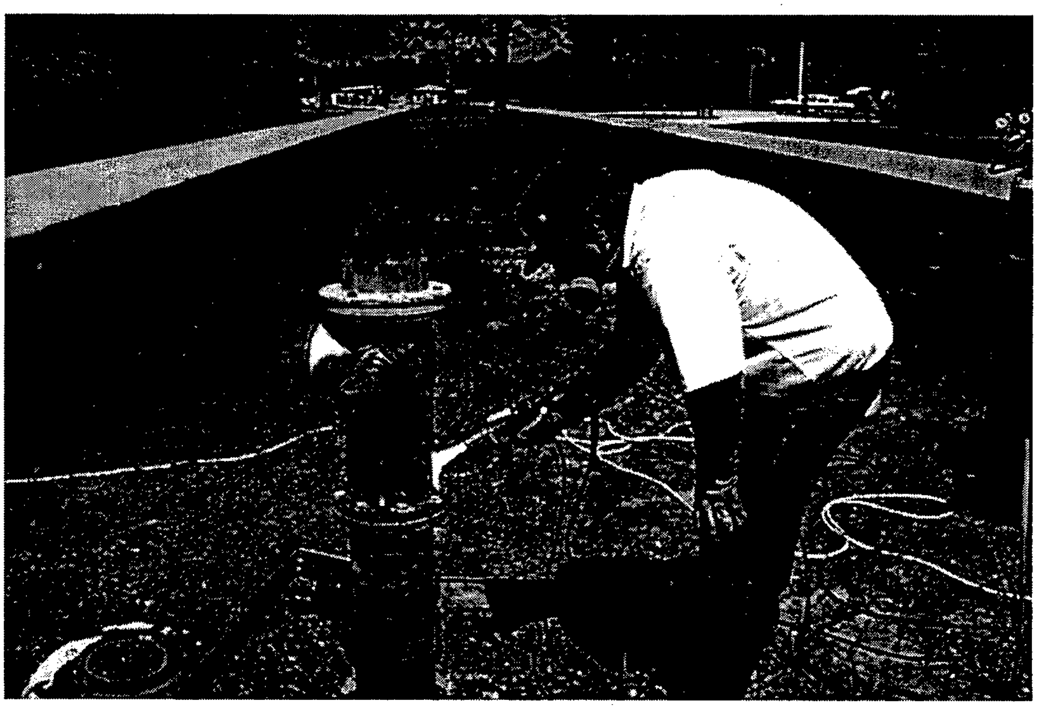

Figure F- 6. TSV application on hydrant near Building 6029.

Figure F- 7. Wire brush cleanup of hydrant near Building 6029 after TSV application.

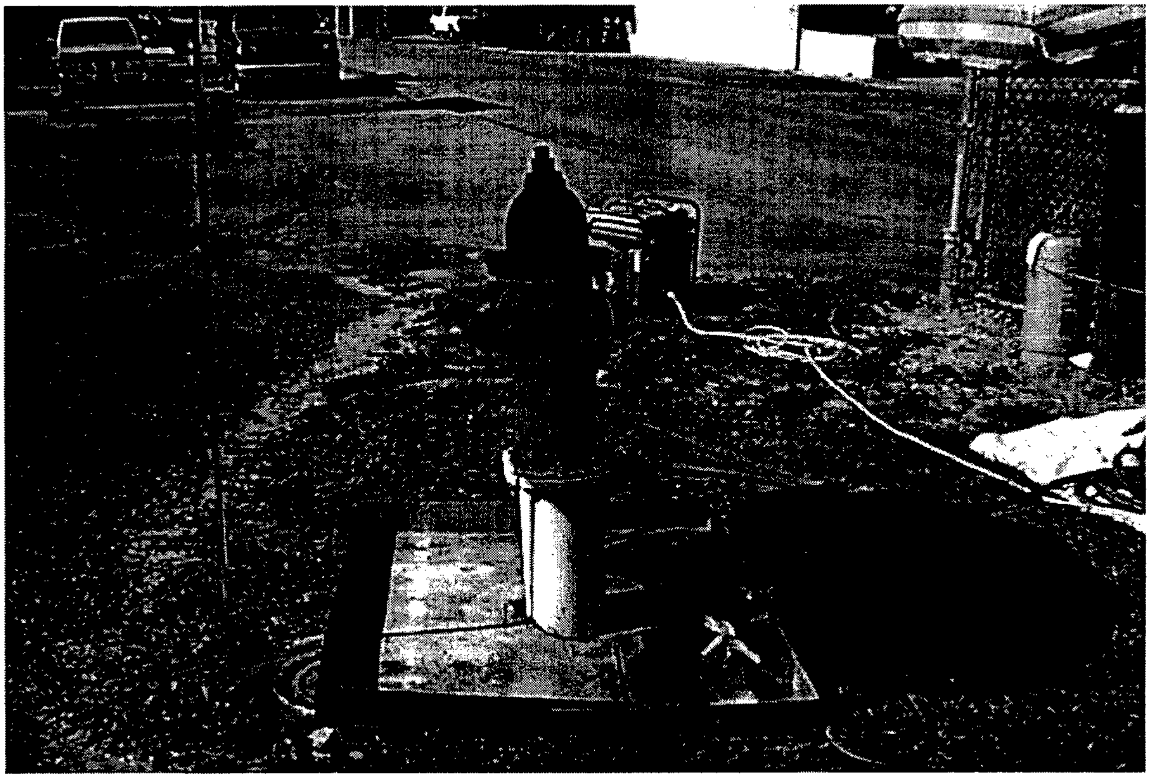

Figure F- 8. Hydrant near building 6027 ready for TSV application.

Figure F- 9. Remelt furnace with glass from both hydrants.

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